STUDY OF AXIAL FORCE OF MARINE PROPELLER

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MASTER OF TECHNOLOGY

By
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CERTIFICATE

It is certified that this work 'STUDY OF AXIAL FORCE OF MARINE PROPELLER' has been carried out under my supervision and that this has not been submitted elsewhere for a degree.

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NOMENCLATURE

A_1	Cross sectional area at section I, (m^2), constant
A_2	Constant
a, b	Exponents
C, C_2, C'_2, C_3	Constant
c	Exponent
D	Vessel diameter, (m)
d	Propeller diameter, (m)
d_d	Draft tube diameter, (m)
d_1^+	Diameter of region of the first turn of liquid at vessel bottom (m)
d_2^+	Diameter of circle, at which the second turn of liquid at vessel bottom and wall begins (m)
$(d_1^+)_{max}$	Maximum value of the quantity d_1^+ (m)
$E_u = \frac{F_{ax}}{\rho n^2 d^4}$	Dimensionless axial force component in the mixed system
e	Exponents
F_{ax}	Axial force component in the system mixed (N)
F_1	Axial force caused by the first liquid turn on the vessel bottom (N)
F_2	Axial force, resulting from the contraction of flow area of the stream flowing along the vessel bottom by external forces (N)
F_3	Axial force caused by the second liquid turn at the vessel bottom and wall (N)
F_4	Axial force caused by the liquid friction in the boundary layer at the vessel wall and the radial baffles(N)

H Height of liquid surface when at rest (m)

h Vertical distance of propeller centre from the vessel bottom (m)

h_d Height of draft tube from the vessel bottom (m)

h_{max} Maximum value of quantity h (m)

K_p Dimensionless pumping capacity of mixer

$K_{bt_1} = \frac{V_{bt_1}}{nd^3}$ Dimensionless flow rate number for region of first liquid turn at the vessel bottom

$K_{bt_3} = \hat{V}_{bt_3}/nd^3$ dimensionless flow rate number for region of second liquid turn at the vessel bottom and wall

L Fundamental dimension for length

M Fundamental dimension for mass

m_{bt} Mass flow rate at vessel bottom

n Rotational speed of mixer (S^{-1})

P, Q, R Exponents

$Re = \frac{\rho n d^2}{\mu}$ Reynolds number

S Exponent

T Fundamental dimension for time

U, V Exponents

V_{bt_1} Volumetric flow rate in region of the first liquid turn at vessel bottom (m^3 sec^{-1})

$\hat{V}_{bt_3}$ Volumetric flow rate in region of the second liquid turn at vessel bottom and wall (m^3 sec^{-1})

$\bar{v}_1$ Mean velocity of liquid at Section I ($m\ s^{-1}$)

$\bar{v}_{1\ ax}$ Mean axial velocity of liquid at Section I ($m\ s^{-1}$)

$\bar{v}_{11\ ax}$ Mean axial velocity of liquid at Section II ($m\ s^{-1}$)

ABSTRACT

The present work is concerned with the forces with which a liquid acts on the vessel bottom when a propeller agitator is used for mixing. From the experimentally observed distribution of dynamic pressure over the vessel bottom it is possible to estimate the axial component of the force by surface integral of such experimentally determined local axial pressures over the vessel bottom by using the concept of a free liquid jet striking a flat plate. The rate of change of axial momentum would give the axial thrust. The axial force could also be directly determined by weighing the vessel with the mixed charge. From the results of these measurements as functions of property and geometry of the system the character and trends of the convective flow of the mixed liquid at the vessel bottom has been interpreted. The amount of liquid striking the vessel bottom is compared with the pumping capacity of the agitator used. Empirical relations have been developed to incorporate the effects of geometry of the system and Reynolds number.

CHAPTER 1

INTRODUCTION

The flow pattern produced within a fluid medium stirred by an impeller in a tank depends on the type of impeller being used. Mixers or impellers generate in the fluid axial flow, radial flow or a flow with mixed characteristics. Marine propeller are known to have axial mixer character. A rotating propeller agitating a fluid in a tank can be considered to be a circular origin, from which a free jet originates and issues forth. The free jet on its traverse is converted into a wall jet when the streaming liquid turns its direction and tends to flow along the tank bottom before finally turning again to flow up along the tank walls. The interaction between the oncoming free jet while it takes a complete turn, produces an axial force field. The determination of axial force component on the tank bottom is relatively easy and canbe made without interfering in the system. Such results can be related to the power input of the mixer, pumping capacity or to the total flow of the mixed liquid.

CHAPTER 2

PREVIOUS PUBLISHED WORK

Theoretical [1] and experimental studies [2-4] so far, have been made for the tangential force component (to be exact: for its moment) by which the mixed charge acts on the vessel or mixer. Other force components of the mixed liquid acting on the vessel have almost not yet been studied despite the fact that especially the axial force component, which can be easily measured, provides valuable information on the flow. Hixson and Baum [5] have reported the existence of axial force component with inclined blade mixers. Hruby and Zaloudik [6] employing axial mixers like marine propellers and inclined blade agitators made systematic measurements on axial thrusts. They used the weighing of the mixed charge with different geometrical and physical properties of the mixed system. Cylindrical vessels with four radial baffles were always used. They correlated the results in terms of dimensionless groups, obtained from dimensional analysis, in the form.

$$E_u = \frac{F_{ax}}{\rho n^2 d^4} = f\ (R_e)$$

where F_{ax} = axial force on the vessel bottom

n = RPM of the rotating impeller

d = diameter of the impeller

ρ = density of the liquid

μ = viscosity of the liquid

$R_e = \frac{\rho n d^2}{\mu}$ (Reynolds number)

They found the dimensionless quantity E_u practically independent of the Reynold's number for Re $> 1.0 \times 10^4$ and decreasing with the decrease of Reynolds number for Re $< 1.0 \times 10^4$. Further they found this quantity dependent on the mixer type and on the rotor distance from the vessel bottom, however, they found it relatively independent of the relative dimensions of the mixer. Fort and Tomes [7] described a method for measuring the distribution of axial dynamic pressure over the flat bottom of a cylindrical baffled mixing vessel with a marine propeller. By applying the momentum theorem to a free jet striking a solid plane wall, the experimental results were interpreted so that a picture of the flow at the vessel bottom was obtained. The liquid pressure on the bottom can be used as a basis for the determination of the axial component of the forces created by the agitator. The amount of liquid striking the vessel bottom was compared with the pumping capacity of the agitator used and a model of the convective flow in the space below the agitator was presented. Later Fort, Eslamy and Kosina [8] extended the work to present rather a comprehensive study of the mixing studies by Fort and Tomes. They estimated the axial component of the force by the surface integral of experimentally determined local axial pressures over the vessel bottom and also directly by weighing the vessel with the mixed charge.

The results were correlated between axial flow and intensity of convective flow of the mixed charge.

The basic purpose of the present work is to study more on the convective flow character of the liquid at the tank bottom. The ensuring interpretation, it is hoped would throw more light on this topic, besides confirming the findings of the earlier workers. This would include the induced flow behaviour at the bottom in presence of a draft tube. Thus, following the technique proposed by Fort and Tomes the present work was concerned with the measurement of forces with which the stirred liquid acts on the vessel bottom when a propeller agitator is used for mixing. From the experimentally determined distribution of dynamic pressures over the vessel bottom, it is anticipated that by using the concept of a free liquid jet striking a flat plate, the volumetric flow rate of the liquid at the vessel bottom may be calculated. This value may then quantitatively be compared with the pumping capacity of the agitator or the volumetric flow rate along the tank walls.

CHAPTER 3

UNDERLYING PRINCIPLES

3.1 Convective Flow Character at the Vessel Bottom:

A typical flow pattern, generated in a fluid medium being stirred by a symmetrically placed propeller in a cylindrical vessel with a flat bottom and three radial baffles is shown in Figure 1 and the corresponding typical profile of axial pressure along a radius for a particular geometrical arrangement of the system is shown in Figure 2. Each curve in Figure 2 corresponds to a certain rotational speed of the mixer. The curves with successively larger differences between their maximum and minimum points corresponds to successively higher rotational speeds. The Figure 2 indicates how the liquid flows near the bottom. The points A, B and C of the radial profiles apparently indicate sudden changes in the flow direction. The area of the vessel bottom can therefore be divided into four regions differing in direction of flow above them. The first region is bounded by a circle about the bottom axis, whose radius equals the distance of point C from the axis. The angle with which the stream approaches the bottom varies over this region and can be determined, for example, by following the traces of fine particles of aluminium.

The outer periphery of the second region is represented on the radial pressure profile by the point A. From the

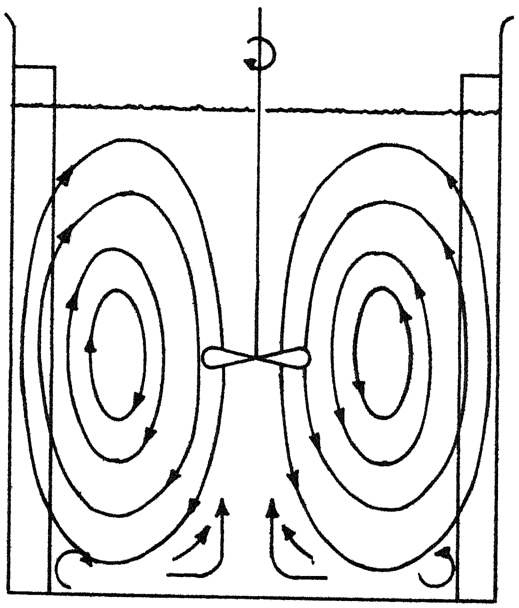

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Fig 1 - Flow pattern in a baffled, propeller agitated tank

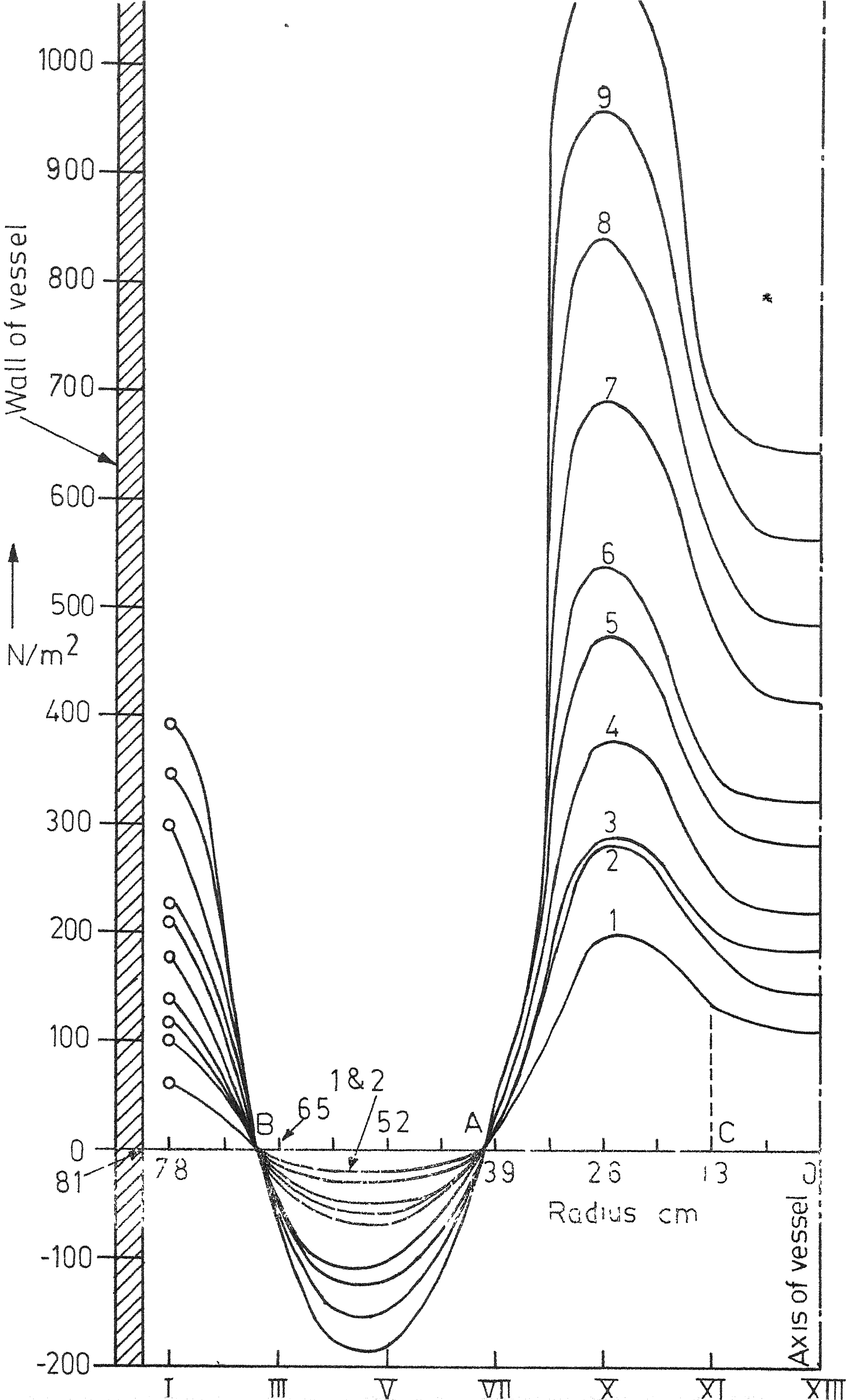


Fig 2 -Axial profiles of pressure on bottom along a radius

Curve 1 2 3 4 5 6 7 8 9 10

experimental results it follows that the distance of point A from the centre does not vary with the orientation of the radius along which the pressure profile is measured. The second region, therefore, has the form of an annulus, at the outer periphery of which the change in the direction of the stream is just completed - all its particles now move in parallel with the vessel bottom. The angle of approach can be taken with sufficient accuracy as constant over this region, which follows from the fact that the distance of the points A and C from the vessel axis is directly proportional to the distance between the centre of the agitator and the bottom of the vessel.

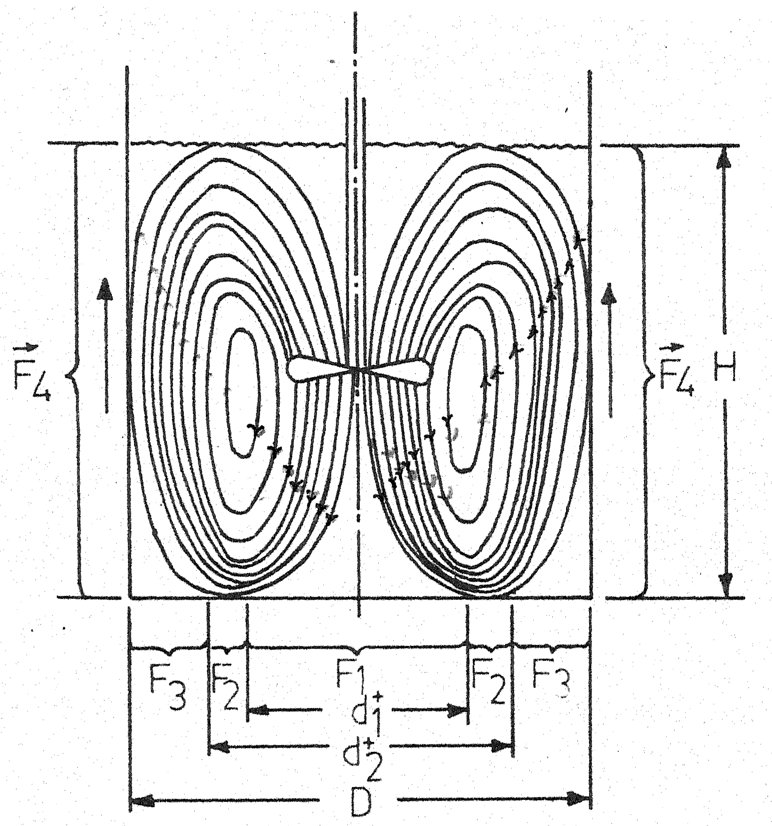
The inner boundary of the third region is formed by a circle of a radius equal to the distance of point A from the vessel axis, and its outer boundary is the closed curve on which the points B are located. Since it was found that the pressure is negative over this region, a fact which can only be explained by flow along the vessel bottom, it can be assumed that the flow over this region is in parallel with the bottom of the vessel.

The border lines of the fourth region are the above mentioned closed curve formed by the inner periphery of the vessel and the baffle edges located on it, over this region, the stream turns upwards along the vessel wall. This change of direction by practically 90° produces over this region of

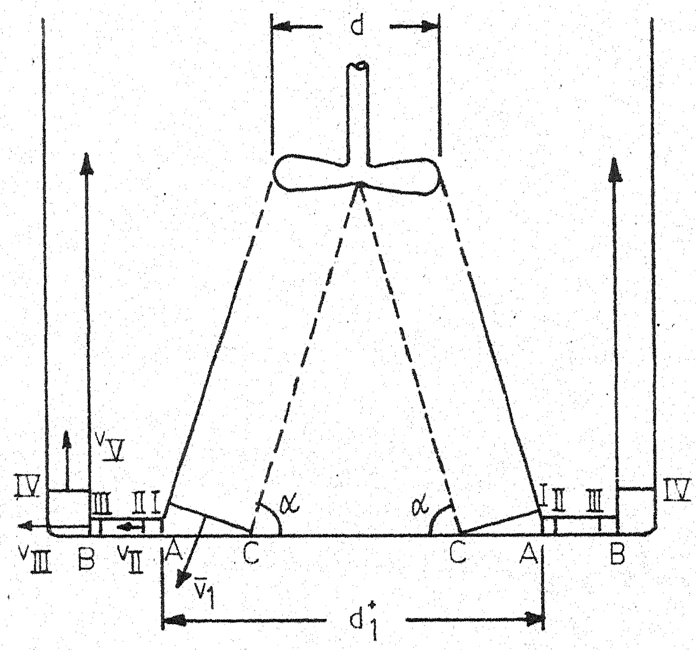
the vessel bottom a reaction which ideally, should be equal to the action of the given volume of liquid flowing towards the bottom over the first and second regions. Actually, however, considerable friction losses occur as the liquid flows along the bottom, and the force effect of this second turning of the stream will be less than that of the first turning under the mixer.

3.2 Forces in Stirred Tank by Axially Placed Propeller:

Figure 3 represents a simplified picture of the flow pattern generated in a fluid medium in a cylindrical vessel and the regions where different forces act. If the weight of the mixing vessel and charge is considered to be the reference force, then the vertical force components acting on the vessel can be expressed as follows: In Figure 3, force F_1 originates when the fluid jet streaming downward from the mixer-rotor deviates from its direction and flows along the vessel bottom. Force F_3 appears in the region where the liquid flowing along the vessel bottom changes its direction and starts flowing upward the cylindrical vessel walls. Both forces are given by the impulse theorem for the free liquid jet by the change of the vertical momentum component occurring in the region of the direction - change with time. F_2 is the force of pressure on the vessel area considered. If we imagine that the liquid stream flowing in this region horizontally in a radial direction is the one which also produces forces F_1 and



3 -Action of axial force component for mixing with an axial mixer, axiall located in cylindrical vessel with radial baffles.



4 -Convective flow at vessel bottom; propeller mixer in baffled vessel.

F_3, it can be assumed - by the Bernoulli Equation (9) that the force F_2 is proportional to the squared volumetric flow rate of the liquid in the stream mentioned. Force F_4 originates from internal friction in the liquid, especially, in the boundary layer at the vessel walls and at the baffles.

3.3 Volume of the Liquid Transported by the Propeller to the Bottom of the Vessel:

For calculating the volume of liquid transported by the propeller to the bottom of the vessel, the expression for a free jet of liquid striking a flat plate obliquely under a constant angle of approach can be used. Figure 4 represents a simplified description of stirred liquid as compared to Figure 3. In it, the angle of approach α is taken constant throughout the region I and II. Although α varies in region I, yet it is taken constant at value corresponding to region II because the area of region I is about 10 per cent that of region II and therefore variation effects in region I can be ignored.

The axial component of the force with which the stream acts on the vessel bottom over the I and II region is equal to the axial component of the change in the momentum of the stream between the section I and II (Figure 4) assuming that between the two sections no external forces act on the stream

$$F_1 = m_{bt} (\bar{v}_{I\ ax} - \bar{v}_{II\ ax}) \qquad (1)$$

where F_1 = axial force caused by the first liquid turn on the vessel bottom

m_{bt} = mass flow rate at vessel bottom

$\bar{v}_{I\ ax}$ = mean axial velocity of liquid at section I

$\bar{v}_{II\ ax}$ = mean axial velocity of liquid at section II

since $\bar{v}_{I\ ax} = \bar{v}_I \sin \alpha$ (2)

where $\bar{v}_I$ = mean velocity of liquid at section I

and $\bar{v}_{II\ ax} = 0$ (3)

Now substituting the values of $\bar{v}_{I\ ax}$ and $\bar{v}_{II\ ax}$ in equation 1, we get

$$F_I = m_{bt}\, \bar{v}_I \sin \alpha \tag{4}$$

$$m_{bt} = \rho\, V_{bt_1} \tag{5}$$

where V_{bt_1} is the flow rate of stream striking the vessel bottom and ρ is the density of the liquid.

so equation (4) can be written as

$$F_1 = \rho\, V_{bt_1}\, \bar{v}_1 \sin \alpha \tag{6}$$

On denoting the outer diameter of the second region by d_1^+ (Figure 3) twice the distance of point A from the axis of the vessel, then the cross sectional area of the stream at the section I will be

$$A_1 = \frac{\pi}{4} (d_1^+)^2 \tag{7}$$

The volumetric flow rate along the axis of vessel will be

$$V_{bt_1} = A_1\, \bar{v}_{I\ ax} \tag{8}$$

On substituting the values of A_1 and $\bar{v}_{I\ ax}$ from Equations (7) and (2) respectively, we get

$$V_{bt_1} = \frac{\pi}{4} (d_1^+)^2 \quad \bar{v}_1 \ \mathrm{Sin}\ \alpha \tag{9}$$

Now substituting the value of $\bar{v}_1$ Sin α from Equations (9) to Equation (6), we get

$$F_I = \rho\, V_{bt_1} \times \frac{4\ V_{bt_1}}{\pi (d_1^+)^2} \tag{10}$$

or

$$V_{bt_1}^2 = \frac{\pi}{4} \times \frac{(d_1+)^2}{\rho} F_I \tag{11}$$

F_I in above equation can be calculated from the distribution of axial pressures by graphical integration over a circle of diameter d_1^+.

or

$$F_I = 4\rho \frac{V_{bt_1}^2}{\pi (d_1^+)^2} \tag{12}$$

A similar relation can be written for the liquid flow rate V_{bt_3} which turns upwards at the vessel wall and for the force F_3 acting on the vessel bottom

$$F_3 = 4\rho\, V_{bt_3}^2 / \pi\ [D^2 - (d_2^+)^2] \tag{13}$$

where F_3 = axial force caused by the second liquid turn at the vessel bottom.

V_{bt_3} = volumetric flow rate in region of the second liquid turn at the vessel bottom and the wall

d_2^+ = diameter of a circle, at which the second turn of the liquid at the vessel bottom begins.

The volumetric flow rate at the vessel bottom V_{bt_1} and V_{bt_3} can be expressed by the use of the dimensionless group K_{bt_1} and K_{bt_3} respectively. The K_{bt_1} and K_{bt_3} are defined as

$$K_{bt_1} = \frac{V_{bt_1}}{nd^3} \tag{14}$$

and

$$K_{bt_3} = \frac{V_{bt_3}}{nd^3} \tag{15}$$

where n is rotational speed of the propeller

d is diameter of the propeller

3.4 Dimensional Analysis:

The behaviour of a liquid being agitated by a propeller or turbine in a tank with a free liquid surface is very complicated and cannot be predicted by an analytical solution of the equations of motion. The technique of dimensional analysis is therefore useful and we now apply it to our system as follows:

$$F_{ax} = f(\rho^P, n^Q, d^R, D^S, \mu^U, h^V) \tag{16}$$

where F_{ax} = axial force acting on the vessel bottom

ρ = density of the solution

n = rotational speed of propeller

d = diameter of propeller

D = diameter of vessel

μ = viscosity of the solution

h = distance of the centre of the mixer from the vessel bottom.

Now writing Equation (16) in terms of three fundamental dimensions, we get

$$\left(\frac{ML}{T^2}\right) = \left(\frac{M}{L^3}\right)^P \left(\frac{1}{T}\right)^Q (L)^R (L)^S \left(\frac{M}{LT}\right)^U (L)^V \qquad (17)$$

The exponents on each variable must be such that the group is dimensionless, so this requires that the following equations be satisfied:

$$\text{For } [M] \qquad 1 = P + U \qquad (18)$$

$$\text{For } [L] \qquad 1 = -3P + R + S - U + V \qquad (19)$$

$$\text{For } [T] \qquad -2 = -Q - U \qquad (20)$$

Now writing P, Q, R in terms of S, U, V from the Equations (18-20), we get

$$P = 1 - U \qquad (21)$$

$$Q = 2 - U \qquad (22)$$

$$R = 4-S-V-2U \qquad (23)$$

Now substituting the exponents values in Equation (16) from equations (21, 22, and 23), we get

$$F_a = \rho^{(1-U)} n^{(2-U)} d^{(4-S-V-2U)} D^S \mu^U h^V \qquad (24)$$

$$F_a = \rho\, \rho^{-U} n^2 n^{-U} d^4 d^{-S-V-2U} D^S \mu^U h^V$$

$$\frac{F_a}{\rho n^2 d^4} = \left(\frac{\rho n d^2}{\mu}\right)^{-U} \left(\frac{d}{D}\right)^{-S-V} \left(\frac{h}{D}\right)^V \qquad (25)$$

Now let $-U = a$ $(-S-V) = b$ and $V = c$ we get

$$\frac{F_a}{\rho n^2 d^4} = \left(\frac{\rho n d^2}{\mu}\right)^a \left(\frac{d}{D}\right)^b \left(\frac{h}{D}\right)^c \qquad (26)$$

Equation (26) expresses the dimensionless group on the left hand side as function of three dimensionless groups $\rho nd^2/\mu$, d/D and h/D. The dimensionless group $F_a/\rho n^2 d^4$ is called Eulers number and $\rho nd^2/\mu$ is called Reynolds number. So Equation (26) can also be written as

$$E_u = f[(Re)^a \quad (d/D)^b \quad (h/D)^c] \tag{27}$$

CHAPTER 4

EXPERIMENTAL EQUIPMENT

The experimental set-up needed for the measurement of axial forces acting on the vessel bottom as the result of mixing by rotating a marine propeller is quite simple. A typical stirred tank configuration is shown in Figure 5. It consists of a cylindrical glass vessel with a flat bottom made of perspex. A Corning glass beaker was taken of which base was removed, and this glass pipe was then inserted in the perspex plate by providing a grove in it. The groove width was kept slightly more than the thickness of glass pipe and the depth of the grove was half the thickness of the perspex plate. Araldite was used for fixing the glass pipe in perspex plate. Three perspex slabs were made and appropriately fixed at the bottom to act as support.

A specified number of holes were provided in the plate in order to insert pressure taps. The length of the pressure taps were in range of 1.5 to 2.0 cm. These holes were on one straight line which start from the centre to the wall of the vessel. A diagram of these holes are shown in Figure 5.

The stirrer shaft was made of S.S. and the length of shaft was kept more than the height of the vessel. The stirrer shaft was properly connected to the motor by providing a hole slightly greater than the diameter of the shaft of the

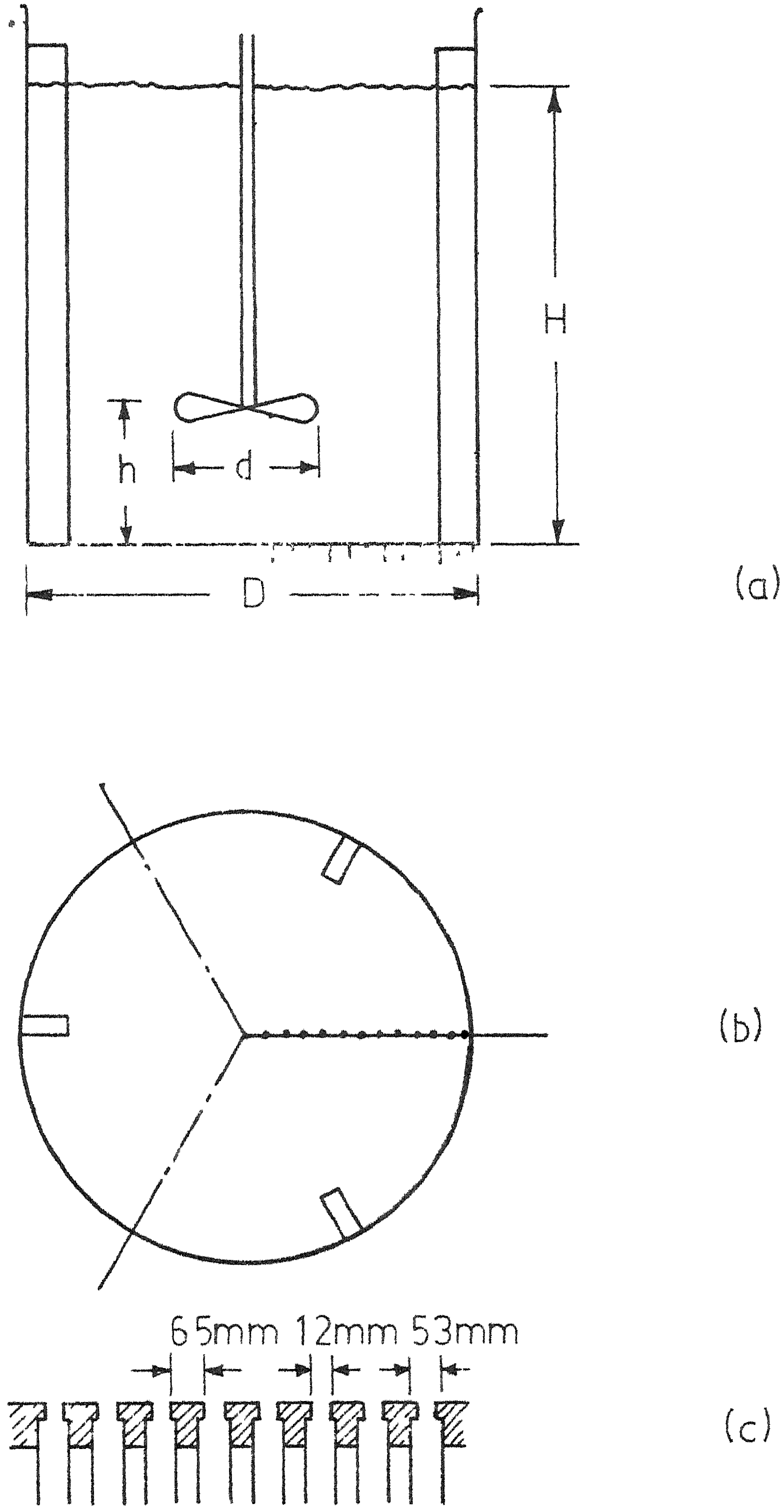


Fig 5 -Schematic drawing of apparatus for measuring distribution of of axial pressures on the vessel bottom

(a) Overall arrangement
(b) Top view
(c) Pressure taps

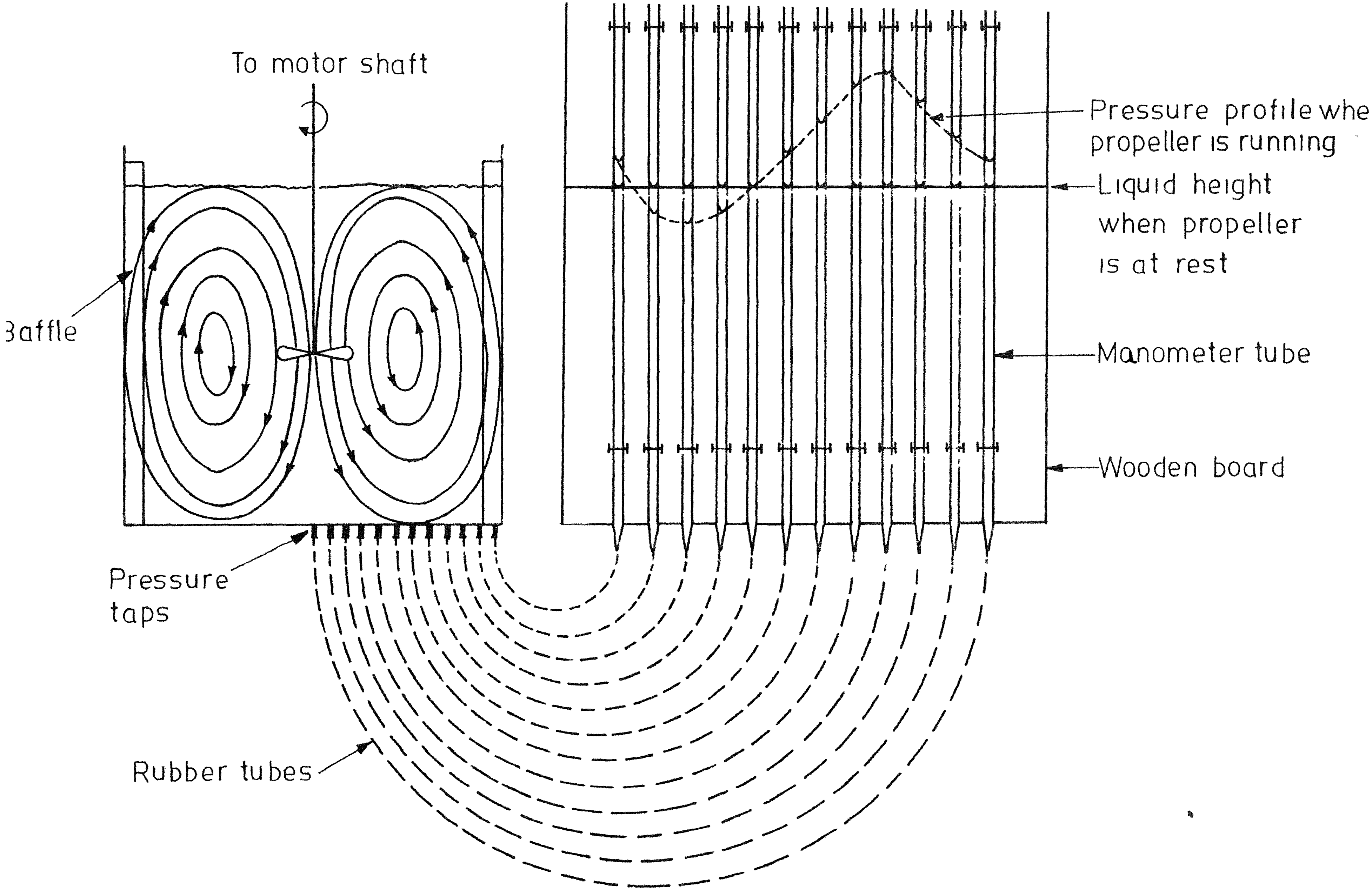


Fig 5A - Experimental set-up

motor. Two threaded holes were provided at the stirrer shaft top through which screws were attached to hold the motor shaft. The other end of the stirrer shaft was made conical in order to locate the centre of the vessel by coinciding the tip of the stirrer shaft to the centre of the vessel. The motor used was 1/15 h.p. D.C. with a speed regulator. The motor was mounted over a drill machine stand. The height of the propeller from the base of the vessel was changed with the help of the drill machine stand. The agitator used was a three blade propeller with a constant pitch. The vessel was provided with three radial baffles whose width was equal to 0.12D, where D is the internal diameter of the vessel. The baffles were made of stainless steel.

The pressure taps were connected to manometer limbs by a good quality of rubber tubings. The manometer tubes were of 12 mm internal diameter and one end of all the tubes were tapered so that the rubber tubings could be inserted in them. The number of manometer tubes were equal to the number of pressure taps provided in thevessel. All manometer tubes were fixed vertically on a wooden board.

Capillaries were inserted in the rubber tubings between the pressure taps and the manometer tubes in order to eliminate oscillations of the surface in the manometric tubes. On doing so oscillations did not die out for the homogeneous solutions of which viscosity is less i.e. upto 25 c.p. and for

higher viscosities these capillaries work very well. In order to damp out the fluctuations for lower viscosity solutions, coils of 5.00 mm. I.D. tube were inserted in place of capillaries. The general form of the vessel bottom was not disturbed by the pressure taps.

The cylindrical vessel was filled with a homogeneous liquid upto the height H which is equal to the vessel diameter D with the mixer at rest. The mixer was always placed at the vessel centre and was rotated in such a direction as to make the liquid flow towards the vessel bottom. The above experimental set-up is used for measuring the pressure at different points on the base of vessel along a straight line which starts from the centre and ends at the wall of the vessel.

The other way of conducting the same experiment was by compensation method - i.e. by measuring the change of the system weight at steady rotation of the mixer and when at rest. Now for measuring the change of the system weight, an ordinary two pan balance was used. On one side of the balance, vessel was placed the centre of which was kept in line with the stirrer centre line and on the other side of the balance weights were kept to bring the balance at null. A locking device was used in the rubber tubings when the compensation method was used. On providing locks to all tubings, the liquid does not fluctuate in the manometer limbs when the stirrer is rotated.

In a few experiments draft tube was also used. The draft tube was made by cutting a glass pipe of diameter 11.50 cm and length 10.50 cm. The baffles were fitted in the tank, which were not inside the draft tube. Small projections in all the baffles were provided so that draft tube could be supported in the vessel. The height of the draft tube from the base of vessel was changed by changing the height of projections in all the three baffles.

CHAPTER 5

EXPERIMENTAL PROCEDURE

5.1 Axial Component of the Force Determined by Local Axial Pressure:

The force by which the stream acts on the bottom of the vessel was determined by measuring the distribution of axial pressures over the bottom. Since the agitated system is symmetrical about three planes, measurements were made only over one third of the area of the vessel bottom. The axial pressures acting on the vessel bottom were measured with manometer in which the mean change in the liquid level was determined by naked eye. The hydrostatic pressure on the vessel bottom was taken as the reference value.

First of all, the vessel was placed at the drill machine stand plate-form. The centre line of vessel was brought in line with the motor centre line. The liquid then filled in the vessel, which rises in the manometer limbs through the rubber tubings. The height of the liquid in the vessel was kept equal to the vessel diameter. The height of liquid in all the manometer limbs does not remain same because of few air bubbles in the rubber tubings. So it is adviseable to make sure that air bubbles are not trapped in rubber tubings. One way of removing air bubbles is to apply pressure on the open side of

manometer till the manometer and rubber tube become empty and liquid gets in the vessel. After this, remove the pressure from the open side of manometer and let the liquid come inside the manometer limb. The same procedure was carried out for all manometer tubes. The other way is to lift the vessel up to the extent it is possible. On doing so air bubbles come up and pass through the open side. The earlier method is quite good and makes 100 per cent sure about the entrapment of air bubbles.

When it is made sure that the vessel centre and the shaft centre are in line and there are no air bubbles, experiment canbe started. Datum line is drawn on the manometer board when the stirrer is kept at rest. The propeller was rotated in such a direction that the liquid flows to the vessel bottom. The readings in the manometer tubes were taken at different speeds within the range of 400 rpm to 1400 rpm by keeping the height of the propeller constant from the base of vessel. The speed of the motor was measured by strobotac. After this the height of the propeller from the base of the vessel was changed and again readings were taken at different speeds. The maximum speed of mixer is such which does not create too much of turbulence at the surface of liquid in the vessel. After this, the propeller was replaced by other propeller and again same procedure was repeated at different speeds and at different heights of propeller from the base of vessel. The same procedure

was repeated with different liquids and geometries.as specified in the experimental program.

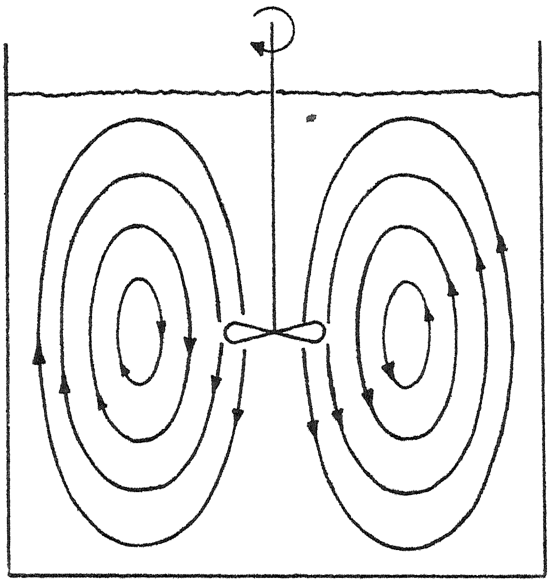
5.2 Axial Component of the Force Determined by Weighing:

The other way of carrying out the same experiment was by compensation method. In this method, first the balance was brought at null position. Here also propeller was placed in the centre line of the vessel. The vessel was filled with one of the liquids and the propeller was rotated in such direction that the flow was towards the bottom. On doing so, the weight of the vessel increased. This increase in weight was balanced by keeping the extra weights on the balance. These readings were taken at different speeds and at different heights of the propeller from the vessel bottom. At higher speeds i.e. at turbulent range too much of fluctuations occur in the balance. In this case different liquids and geometries were used as referred in the experimental program.

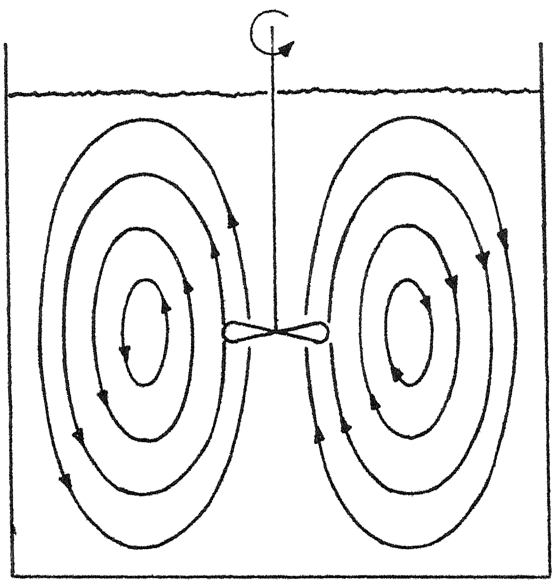
5.3 Axial Component of the Force Determined by Weighing Using Draft Tube:

When the direction of the motor was reversed, the flow of liquid in the vessel reversed and moved towards the surface of liquid i.e. upwards as shown in Figure 6.

On rotating the mixer in anticlockwise direction, the weight of the vessel decreased and in order to bring the balance in null position, the weights were kept on the vessel



| 6(a)- Flow pattern of fluid when propeller running in clockwise direction



g 6(b)- Flow pattern of fluid when propeller running in anticlockwise direction

side. For this case also readings were taken at different speeds and at different heights of the propeller from the base of the vessel. It may be noted that for bigger vessel direct weighing could not be done due to practical difficulties.

The vessel was kept on the balance and the axis of vessel was brought in line with the axis of motor shaft. The draft tube was also fitted at some height from the base of the vessel. The height of the propeller from the base of the vessel was maintained constant. The increase and decrease in the weight by rotating the propeller clockwise and anticlockwise respectively was found out at different speeds. Now keeping the height of the draft tube same as it was earlier, the height of propeller from base of vessel was changed and at different heights of propeller same readings were taken as mentioned above. Now the height of the draft tube from vessel bottom was increased, and again readings were taken at different heights of the propeller from the base of the vessel at different speeds of propeller.

The accuracy and reproducibility of axial pressure and weighing measurements by the above described procedure is mainly influenced by the following factors:

1. The eccentricity of the mixer with respect to the vessel axis
2. The accuracy with which the mixer is placed at the desired height above the bottom of the vessel.

3. The constancy of the rotational speed of the mixer and the temperature of the liquid.
4. The oscillations of the liquid level in the manometric tubes.
5. Sensitivity of the balance used and the weights of the weighing box.

With a view to the required accuracy of the results, it was necessary to repeat measurements at least for 4 times and then their arithmetic mean was taken as the value for the given conditions.

The independent variables in these experiments were:

1. The rotational speed n of the mixer
2. The kinematic viscosity μ/ρ of the liquid
3. The diameter d of the propeller
4. The diameter D of the vessel, and
5. The height of the propeller h above the bottom of the vessel.

The dependent variable was the mean value of the local axial pressure. The independent variables were in our measurements subjected to practically negligible error as compared to the error with which the dependent variable was measured. The independent quantities in both experimental series were the rotational speed of the mixer n, kinematic viscosity μ/ρ of the liquid, mixer diameter d, distance of the mixer from the vessel bottom h, the vessel diameter and the height of the draft tube from the vessel bottom h_d.

CHAPTER 6

EXPERIMENTAL PROGRAMME

The experimental programme mainly deals as mentioned earlier, in correlating the Euler's number (E_u) and Reynolds number (Re) against various system variables. The basic data involves the pressure measurement at different points on the bottom of the vessel against various parameters. The effects of the following system variables or parameters on Eulers number (E_u) were studied:

1. n, the rotational speed of the propeller in rpm when immersed in the liquid. It varies from 90 rpm to 1700 rpm.
2. d, the diameter of the propeller. Two propellers were used of diameters 6.00 cm and 7.9 cm.
3. D, the diameter of the tank. Two tanks were used of diameters 16.2 cm and 21.5 cm.
4. h, the height of the propeller from the base of the vessel. The heights used in smaller vessel (D=16.2cm) were 1.0, 3.0, 5.0 and 7.0 cm and the heights used in bigger vessel (D=21.5 cm) were 1.0, 3.0, 5.0, 7.0, 9.0 and 13.0 cm.
5. h_d, the height of the draft tube from the base of the vessel. The diameter of which was 11.50 cm and the length was 10.50 cm. The heights used were 1.0, 2.9, 4.1 and 5.3 cm.

6. H, the liquid depth in the tank. The depth was always made equal to the vessel diameter.
7. d/D, the ratio of the diameter of the propeller to the diameter of the vessel.
8. h/D, the ratio of the height of the propeller from the base of the vessel to the vessel diameter.

The experimental study was made on the following systems:

1. Distilled water: (i) Viscosity 0.9820 cp
   (ii) Density 1.0000 gms/cc
   (iii) Room temperature
2. 50 per cent Aqueous Glycerol:
   (i) Viscosity 5.4375 cp
   (ii) Density 1.1463 gms/cc
   (iii) Room temperature
3. 60 per cent Aqueous Glycerol:
   (i) Viscosity 22.1053 cp
   (ii) Density 1.1933 gms/cc
   (iii) Room temperature
4. Mustard Oil: (i) Viscosity 62.8968 cp
   (ii) Density 0.9191 gms/cc
   (iii) Room temperature

Details of Figures:

Figure No.	Run No.	Table No.
2	1	-
8	17, 35, 38 and 48	17, 35, 37, and 47
9	18, 36, 39 and 49	18, 36, 38 and 48
10	1, 2, 3, 4, 19, 20, 21, 22, 40, 41, 42, and 43	1, 2, 3, 4, 19, 20, 21, 22, 39, 40, 41, and 42
11	5, 6, 7, 8, 23, 24, 25, 26, 44, 45, 46, and 47	5, 6, 7, 8, 23, 24, 25, 26, 43, 44, 45 and 46
12	9, 10, 11, 12, 27, 28, 29, and 30	9, 10, 11, 12, 27, 28, 29, and 30
13	13, 14, 15, 16, 31, 32, 33 and 34	13, 14, 15,16, 31, 32, 33 and 34.

CHAPTER 7

ANALYSIS OF DATA

7.1 Calculation of Eulers Number by Pressure Profile:

In the experimental set-up four different solution: distilled water, 50 per cent aqueous glycerol, 60 per cent aqueous glycerol and mustard oil were used. In all the cases Eulers number was calculated at different heights of the propeller from the base of the vessel (h=1.0, 3.0, 5.0 and 7.0 cm) and at different speeds of propeller. The calculation procedure for the Euler's number is same for all the cases. Let us consider distilled water for the calculation of Eulers number:

The details of the experimental conditions are as follows:

1.	Liquid used	Distilled water
2.	Diameter of vessel D	16.2 cm
3.	Diameter of propeller d	6.00 cm
4.	Height of propeller from the base of the vessel, h	1.0 cm
5.	Height of liquid in the vessel, H	16.2 cm
6.	Propeller speed range, n	650 rpm to 1500 rpm
7.	Density of liquid, ρ	1.000 gms/cc
8.	Viscosity of liquid, μ	0.9820 cp

The data observed on running the experiment in above conditions are shown in Appendix II (Run 1). From this i.e.

run 1, dynamic pressures at 13 different points along a radius can be found out.

7.2 Conversion of Pressure from 'cm of water' to Newtons/m^2:

$$1 \text{ atm} = 33.93 \text{ ft of water} \quad (28)$$

or $$33.93 \times 12 \times 2.54 \text{ cm of water} = 1034.1864 \text{ cm of water} = 1 \text{ atm}$$

or $$1 \text{ cm of water} = 1/1034.1864 \text{ atm} \quad (29)$$

$$^{\delta}\ 1 \text{ atm} = 1.0133 \times 10^5 \text{ kg-m/sec}^2 \text{ or Newtons/m}^2$$

$$1 \text{ cm of water} = \frac{1.0133 \times 10^5}{1034.1864} \text{ Newtons/m}^2$$

or $$1 \text{ cm of water} = 97.9170 \text{ Newtons/m}^2$$

First of all the pressure which is in cm of water, is converted into Newtons/m^2 by multiplying it by 97.9170. After this, curves are plotted between pressure which is in N/m^2 as ordinate versus radius which is in cm as absisca taking speed of the propeller as parameter. The curves thus drawn are shown in Figure 2. Distance of point A from the centre line of the vessel corresponds to $d_1^+/2$ and distance of point B from the centre line of vessel gives $d_2^+/2$. Thus we get the values of d_1^+ and d_2^+. From Figure 2 we get $d_1^+ = 8.06$ cm and $d_2^+ = 13.52$ cm.

After this, curves were plotted between the pressure in N/m^2 versus cross sectional area which is in m^2 corresponding to different tap positions in the vessel taking speed of the

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$^{\delta}$Bird, R.B., Stewart, W.E., and Lightfoot, E.N., 'Transport Phenomena' p. 750.

propeller as parameter. These curves thus drawn are shown in Figure 7.

Radius (meter)	Cross-sectional area (meter)^2
0	0
0.65×10^{-2}	1.3267×10^{-4}
1.30×10^{-2}	5.3066×10^{-4}
1.95×10^{-2}	11.9399×10^{-4}
2.60×10^{-2}	21.2264×10^{-4}
3.25×10^{-2}	33.1663×10^{-4}
3.90×10^{-2}	47.7594×10^{-4}
4.55×10^{-2}	65.0059×10^{-4}
5.20×10^{-2}	84.9056×10^{-4}
5.85×10^{-2}	107.4587×10^{-4}
6.50×10^{-2}	132.6650×10^{-4}
7.15×10^{-2}	160.5247×10^{-4}
7.80×10^{-2}	191.0376×10^{-4}

In Figure 7, the area of the part of the curve between point A and the axis of the vessel gives the value of force F_1 and the area between points A and B gives the force F_2 and the area between the point B and the wall of the vessel gives the force F_3. The magnitude of the force F_4 was considered negligible. Thus the total axial force at the bottom of the vessel becomes

$$F_{ax} = F_1 - F_2 + F_3 \tag{30}$$

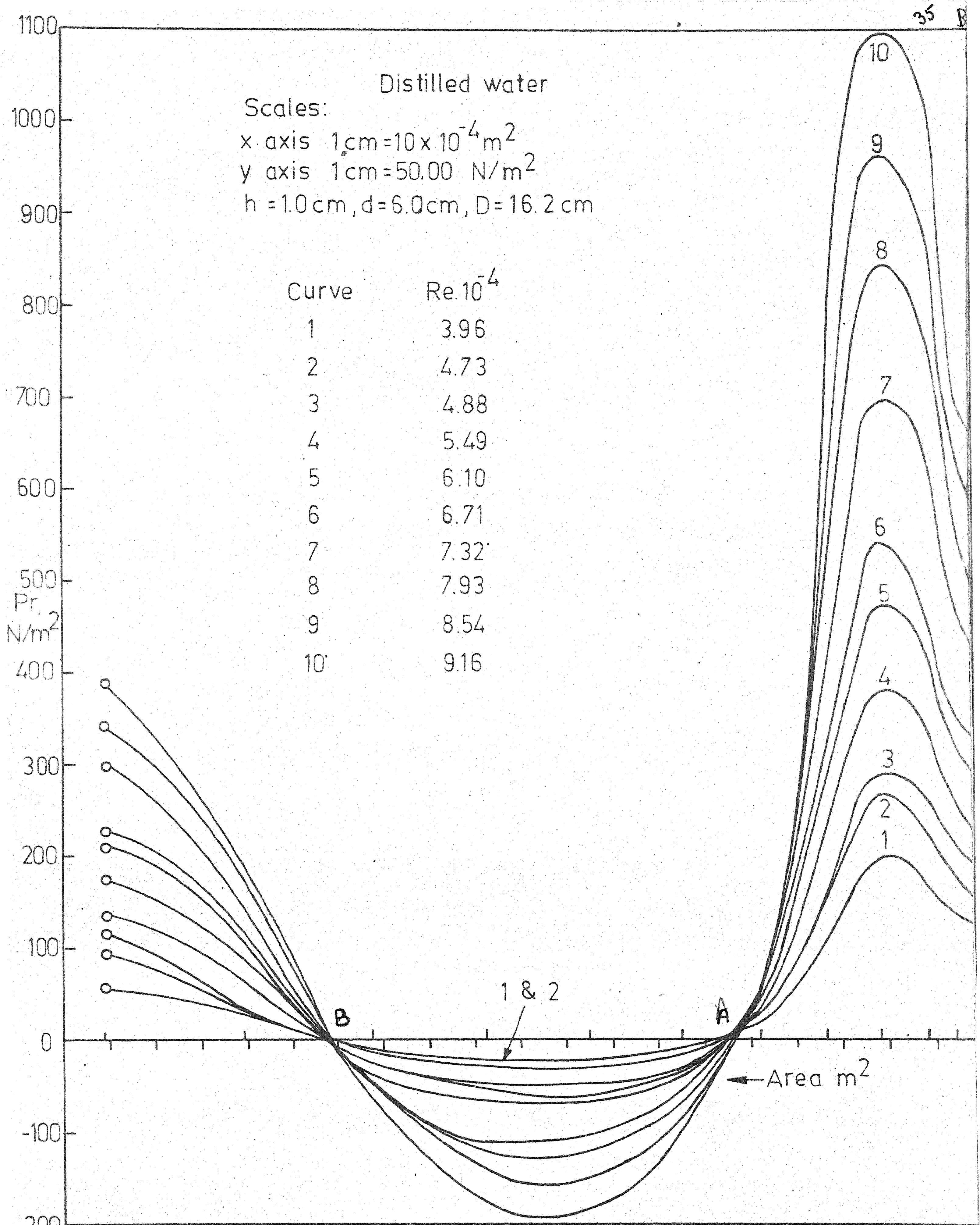


Fig. 7 - Pressure (N/m^2) versus area (m^2).

Thus the area of each curve, which corresponds to a particular speed was found out. This area gives the value of total axial force acting on the vessel bottom. The magnitude of forces F_1, F_2, F_3 and F_{ax} at different speeds are shown in Table 1, Appendix VI.

$$E_u = \frac{F_{ax}}{\rho n^2 d^4} \quad \text{(see 3.4)} \qquad (31)$$

and

$$Re = \frac{\rho n d^2}{\mu} \quad \text{(see 3.4)} \qquad (32)$$

where F_{ax} = total axial force acting at the bottom of vessel

ρ = density of solution

n = rotational speed of the propeller

d = diameter of the propeller

μ = viscosity of the solution

For n=1500 rpm

F_{ax}= 3.5190 kg-m/sec^2 (See Table 1) Appendix VI

ρ = 1.0000 gms/cc

d = 6.0000 cm

μ = 0.9840 cp or gm/cm sec

$$E_u = 3.5190 \frac{\text{Kg-m}}{\text{sec}^2} \times \frac{1}{1} \frac{\text{cm}^3}{\text{gm}} \times \frac{1}{(1500)^2} \text{min}^2 \times \frac{1}{(6.0)^4 \text{cm}^4} \times \frac{10^3}{1 \text{ Kg}} \text{gms}$$

$$\times \frac{60 \times 60 \text{ sec}^2}{\text{min}^2} \times \frac{100 \text{ cm}}{1 \text{ m}}$$

E_u = 0.4348

Corresponding Reynolds number

$$Re = \frac{1\ gm}{cm^3} \times 1500\ \frac{1}{min} \times (6.0)^2 cm^2 \times \frac{1\ cm\ sec}{0.984\ gm} \times \frac{1\ min}{60\ sec}$$

$$Re = 9.1200 \times 10^4$$

In the same way Eulers number and Reynolds number can be calculated at different speeds of propeller. The values are shown in Table 1, Appendix VI.

7.3 Calculation of K_{bt_1} and K_{bt_3}:

$$K_{bt_1} = \frac{V_{bt_1}}{nd^3} \tag{14}$$

and

$$K_{bt_3} = V_{bt_3}/nd^3 \tag{15}$$

For calculating K_{bt_1} and K_{bt_3}, the first thing required is to calculate V_{bt_1} and V_{bt_3}. From equations 12 and 13, we get

$$V_{bt_1} = \left[\frac{F_1 \times \pi \times (d_1^+)^2}{4\rho}\right]^{\frac{1}{2}} \tag{33}$$

$$V_{bt_3} = \left[\frac{F_3 \times \pi \times (D^2-(d_2^+)^2)}{4\rho}\right]^{\frac{1}{2}} \tag{34}$$

The values of d_1^+, d_2^+, D, F_1 and F_3 are given in Table 1 Appendix VI at all speeds. From Table 1 Appendix VI above values at 1500 rpm are:

$d_1^+ = 8.06 \times 10^{-2}$ m

$d_2^+ = 13.52 \times 10^{-2}$ m

$$D = 16.20 \times 10^{-2}\ m$$

$$F_1 = 3.5345\ N/m^2$$

$$F_3 = 1.0955\ N/m^2$$

$$\rho = 1.0000\ gms/cc \text{ or } 1000\ Kgs/m^3$$

So $$V_{bt_1} = \left[\frac{3.5345 \times \pi \times 8.06 \times 8.06 \times 10^{-4}}{4 \times 1000}\right]^{\frac{1}{2}} = 4.2466 \times 10^{-3} m^3/sec$$

and $$V_{bt_3} = \left[\frac{1.0955 \times \pi \times ((16.20)^2-(13.52)^2) \times 10^{-4}}{4 \times 1000}\right]^{\frac{1}{2}}$$

$$= 2.6178 \times 10^{-3}\ m^3/sec$$

Now substituting the values of V_{bt_1} and V_{bt_3} in equations 33 and 34, we get

$$K_{bt_1} = \frac{4.2466 \times 10^{-3}\ m^3 \times min}{1500 \times (6.0)^3\ Sec \times cm^3} \times 10^6\ \frac{cm^3}{m^3} \times \frac{60\ sec}{min}$$

$$K_{bt_1} = \frac{4.2466 \times 10^{-3} \times 10^6 \times 60}{1500 \times (6.0)^3} = 0.7864$$

and $$K_{bt_3} = \frac{2.6178 \times 10^{-3} \times 10^6 \times 60}{1500 \times (6.0)^3} = 0.4848$$

Similarly K_{bt_1} and K_{bt_3} values carbe calculated at different speeds of the propeller. The calculated values at all speeds of the propeller are shown in Table 1 Appendix VI.

7.4 Calculation of Eulers Number by Weighing:

The Eulers number calculation becomes easier by weighing procedure because the increase in the weight of the system due to stirring, gives directly the total axial force

in terms of Kg-mass. By multiplying the weight by acceleration due to gravity, we get axial force in terms of Newtons/m^2 or Kg-m/sec^2.

The change in the weight of the system on rotating the propeller in clockwise direction, at different speeds and at different heights of propeller from the base of the vessel, is given in Appendix II Run 17. Now consider the calculation of Eulers number under the following conditions:

1. Liquid used	Distilled water
2. Diameter of vessel, D	16.20 cm
3. Diameter of Propeller, d	6.00 cm
4. Height of propeller from the base of the vessel, h	1.00 cm
5. Height of the liquid in the vessel, H	16.20 cm
6. Propeller speed range, n	300 rpm to 1400 rpm
7. Density of liquid, ρ	1.000 gms/cc
8. Viscosity of liquid, μ	0.9820 cp

The change in the weight of the system because of rotating the propeller at 1400 rpm is 275.00 gms (see Appendix II Run 17.).

$$E_u = \frac{F_{ax}}{\rho n^2 d^4} \qquad (31)$$

$$E_u = 275 \text{ gms} \times \frac{1 \text{ Kg}}{1000 \text{ gms}} \times \frac{9.81 \text{ m}}{\text{Sec}^2} \times \frac{1}{1} \quad \frac{\text{cm}^3}{\text{gm}} \times \frac{1000 \text{ gms}}{1.0 \text{ Kg}}$$

$$\times \frac{1 \text{ min}^2}{(1400)^2} \times \frac{60 \times 60 \text{ sec}^2}{1 \text{ min}^2} \times \frac{1}{(6.0)^4 \text{cm}^4} \times \frac{100 \text{ cm}}{1 \text{ m}}$$

$$E_u = \frac{275 \times 9.81 \times 1000 \times 60 \times 60 \times 100}{1000 \times 1400 \times 1400 \times 6.0 \times 6.0 \times 6.0 \times 6.0} = 0.3820$$

The Reynolds number calculation as already been shown earlier in this chapter. The Reynolds number at 1400 rpm is 8.54×10^4. The values of Eulers number at different Reynolds number and at different heights of propeller from the base of vessel are shown in Table 17 Appendix VI.

The data which are taken by using distilled water solution are given in Appendix II. In run 1 and run 2 (Appendix II) the pressure is given at all the 13 points but from their onwards the value of pressure is given at 7 points only which covers the radius of the vessel at the base, in order to reduce the volumenous data. For the bigger vessel D=21.5 cm, the pressures were taken at 11 points on the vessel bottom but the pressure value, given in data, are only at 6 point along a radius because of the same reason. From all these data, the Eulers number, K_{bt_1} and K_{bt_3} at different Reynolds number, d_1^+ and d_2^+, were calculated by the same procedure as has been shown earlier (7.1). These calculated values are given in Appendix VI to IX.

CHAPTER 8

RESULTS AND DISCUSSIONS

8.1 Dependence of Eulers Number on Reynolds Number:

Different curves were plotted between Eulers number and Reynolds number by determining the local axial pressures over the vessel bottom and by directly weighing the vessel with the mixed charge. The curve plotted by determining the local axial pressures over the vessel bottom are shown in Figures 10, 11, 12 and 13, and the ones by directly weighing the vessel are shown in Figures 8 and 9. From all these figures it was observed that Eulers number is independent of Reynolds number and remains constant in region $Re > 10^4$. The above result is in agreement with the findings of Hruby and Zaloudik [6] and Fort, Eslamy and Kosina [8]. The behaviour of Eulers number with Reynolds number in the field of $Re < 1.0 \times 10^4$ suggests that the zone is transitional. This is also reported by Novak and Rieger [10]. The laminar zone could not be detected since it occurs at value of $Re < 10$ which could not be reached in the present experiment.

8.2 Dependence of Eulers Number on d/D and h/D:

From the dimensional analysis (3.4), it was shown that Eulers number is a function of Re, d/D and h/D i.e.

$$E_u = f(Re^a, (d/D)^b, (h/D)^c) \qquad (27)$$

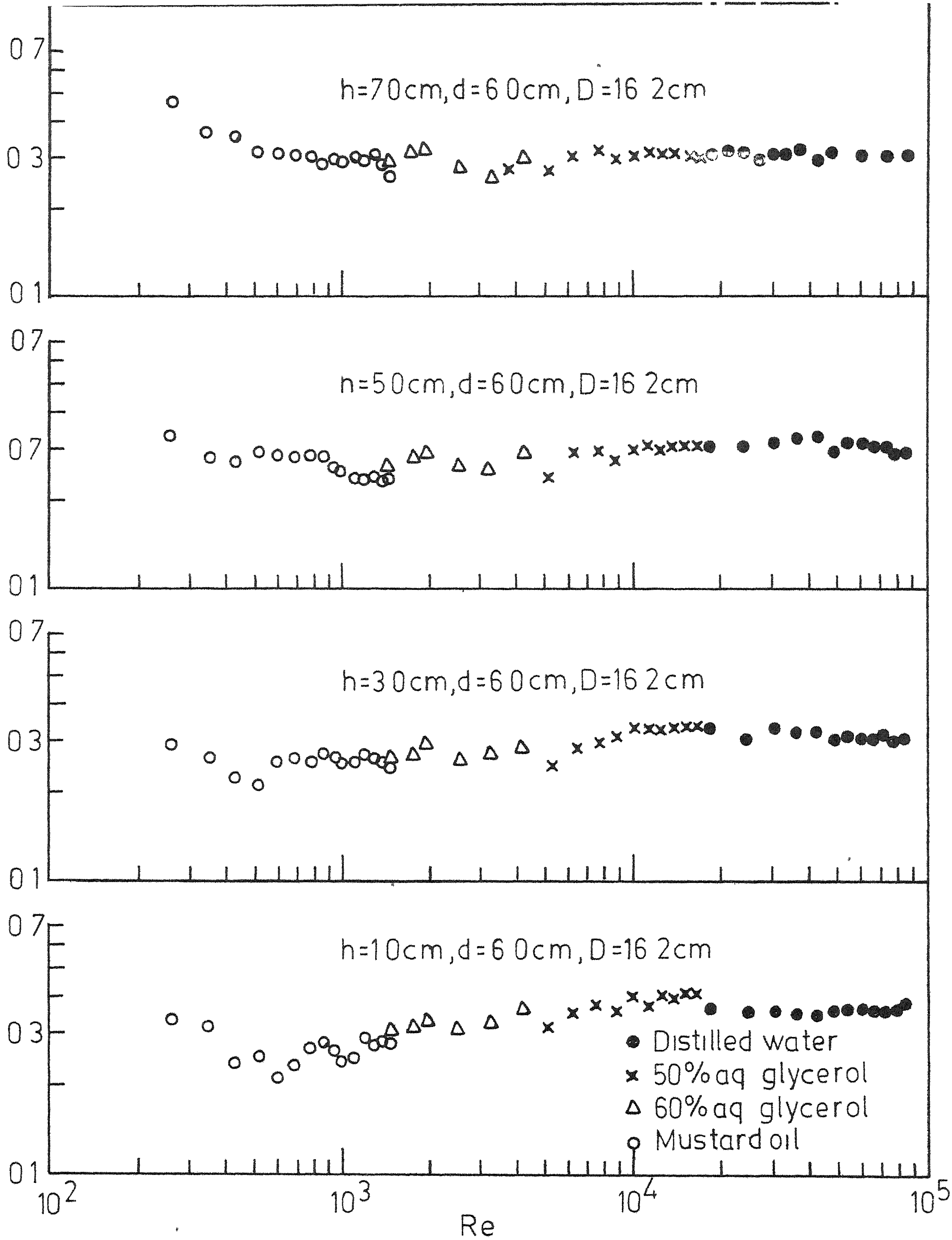
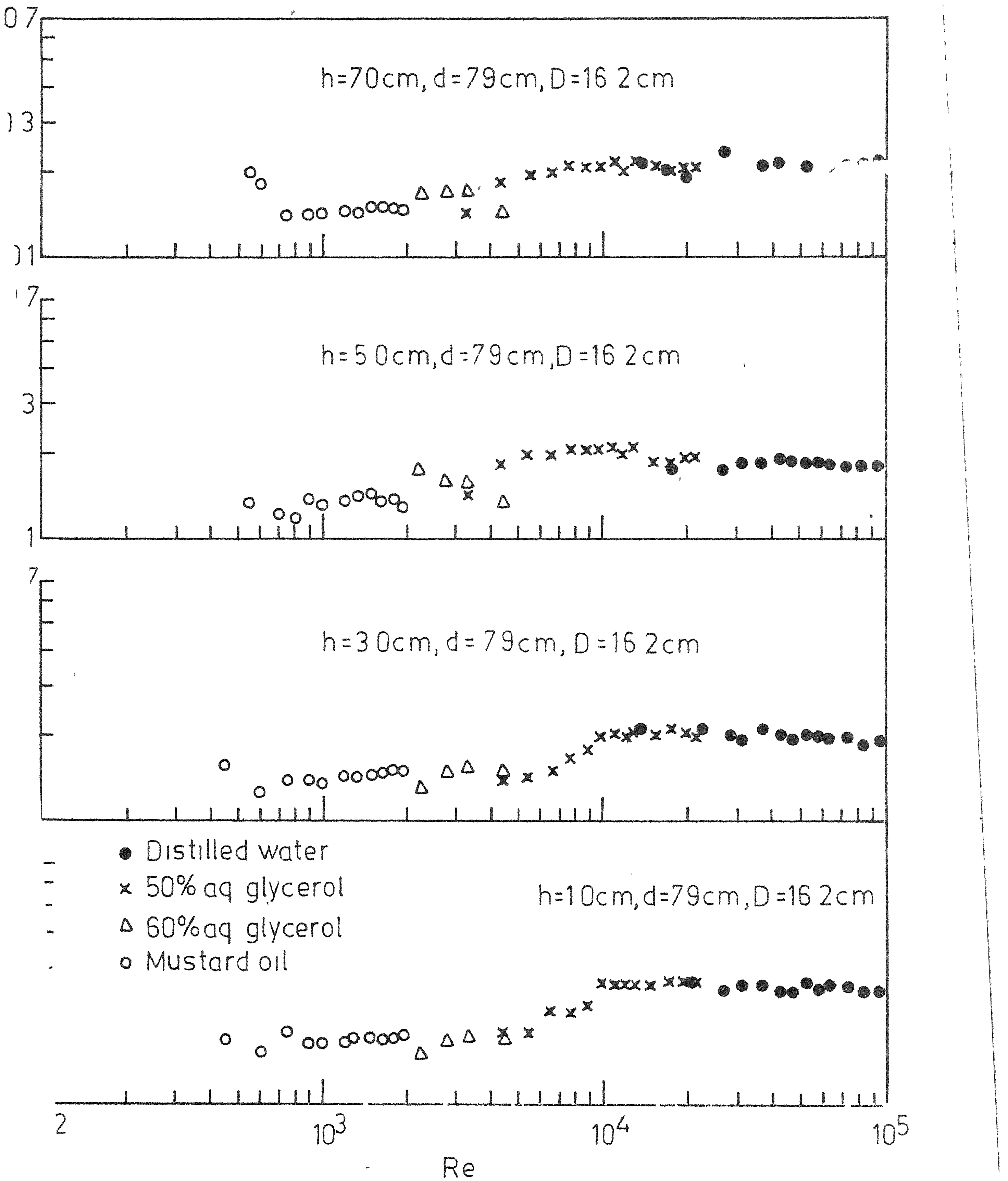


Fig 8 - Dependence of Eu on Re for cylindrical vessel with baffles by weighing



- Dependence of Eu on Re for cylindrical vessels with baffles by weighing

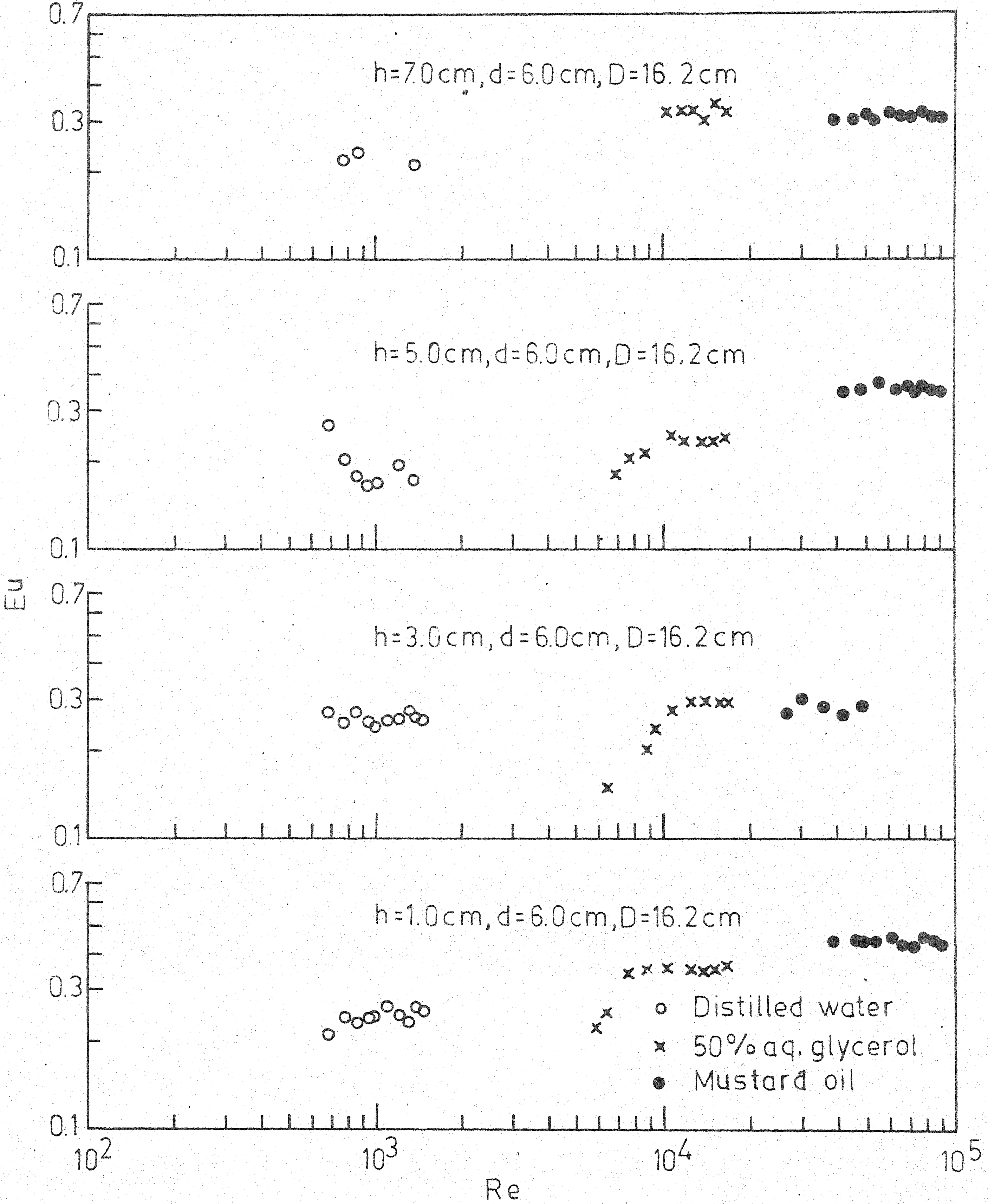
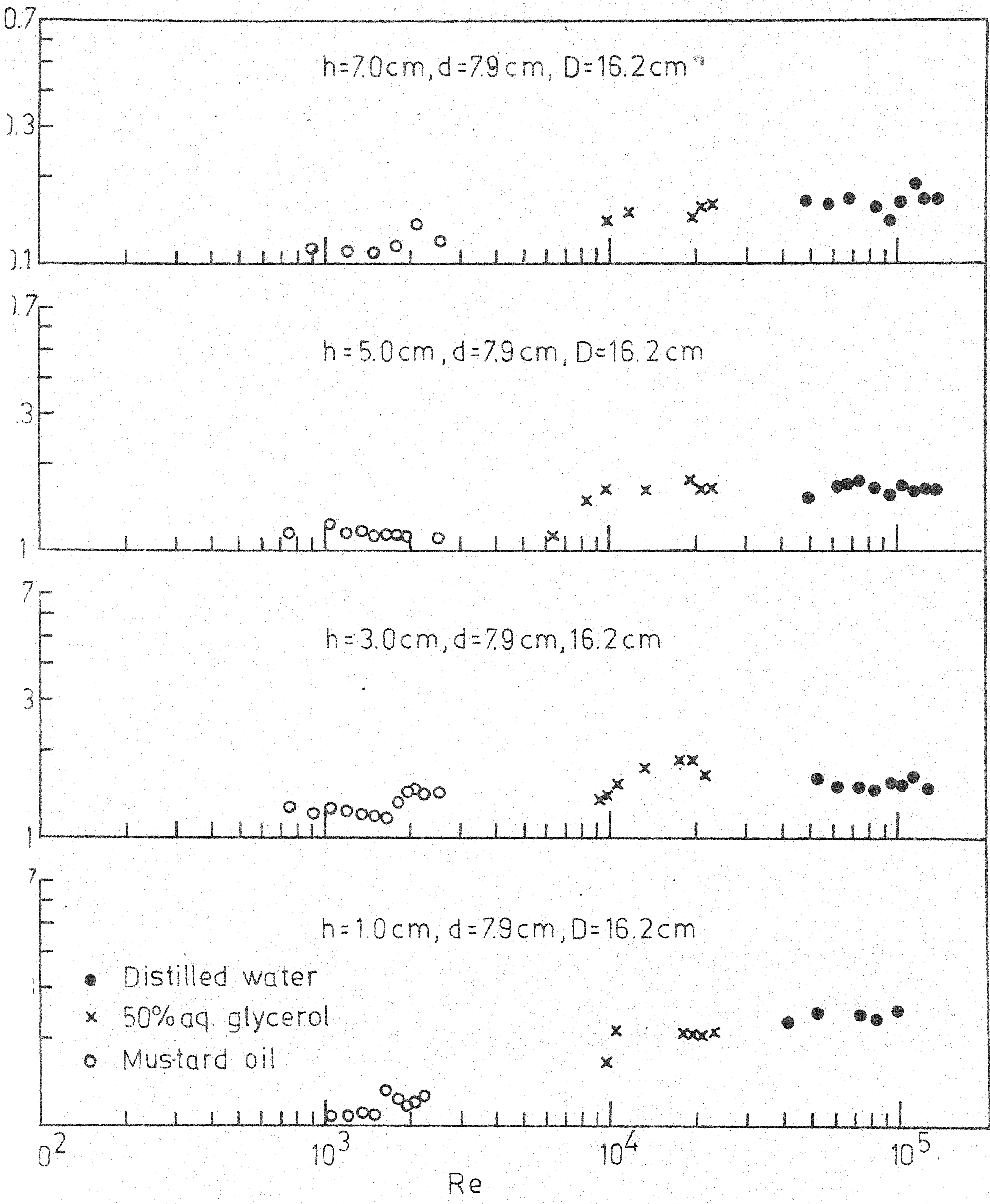


Fig. 10 -Dependence of Eu on Re cylindrical vessels with baffles by pressure profile.



1 - Dependence of Eu on Re for cylindrical vessels with baffles by pressure profile.

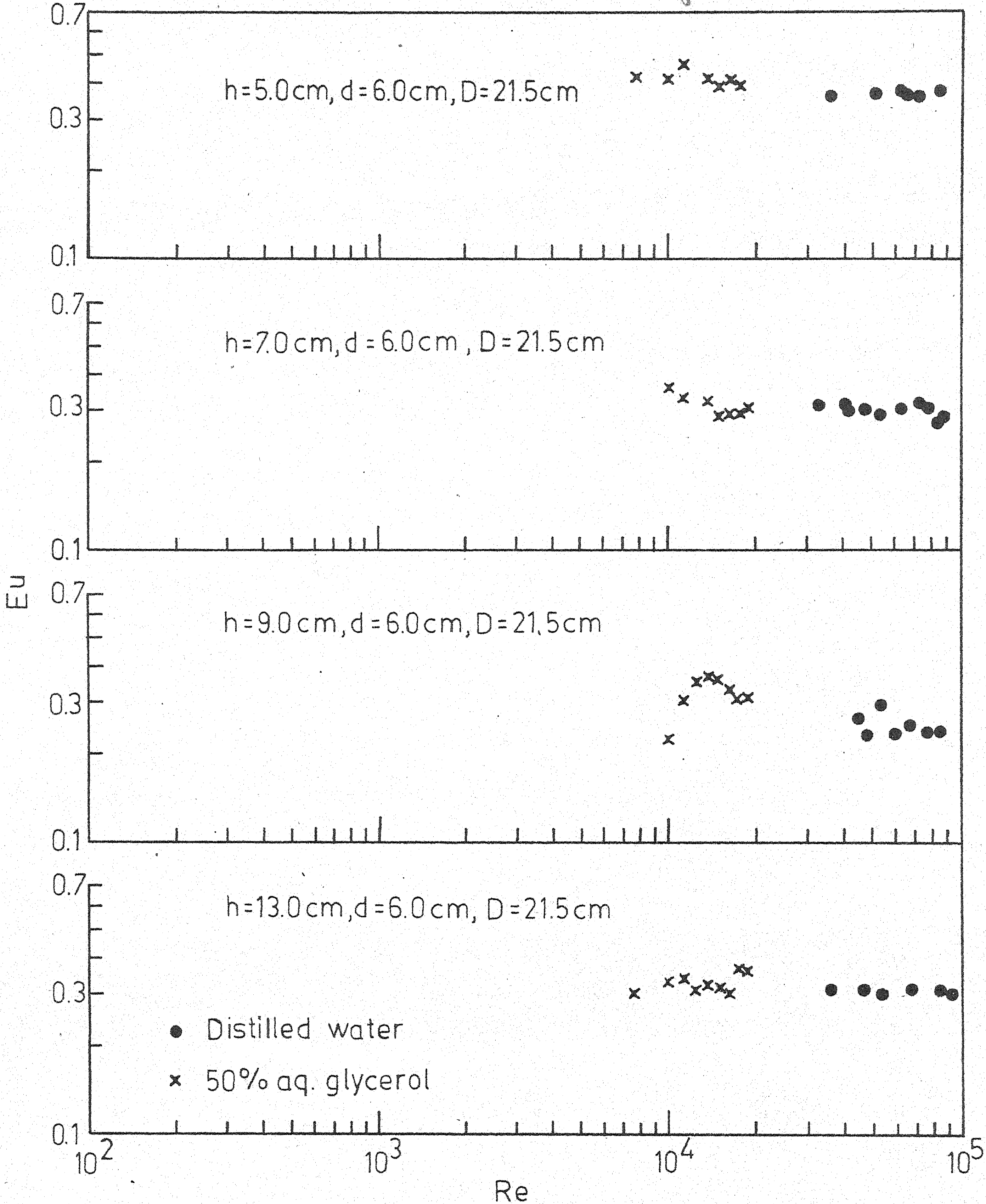


Fig. 12 - Dependence of Eu on Re for cylindrical vessels with baffles by pressure profile.

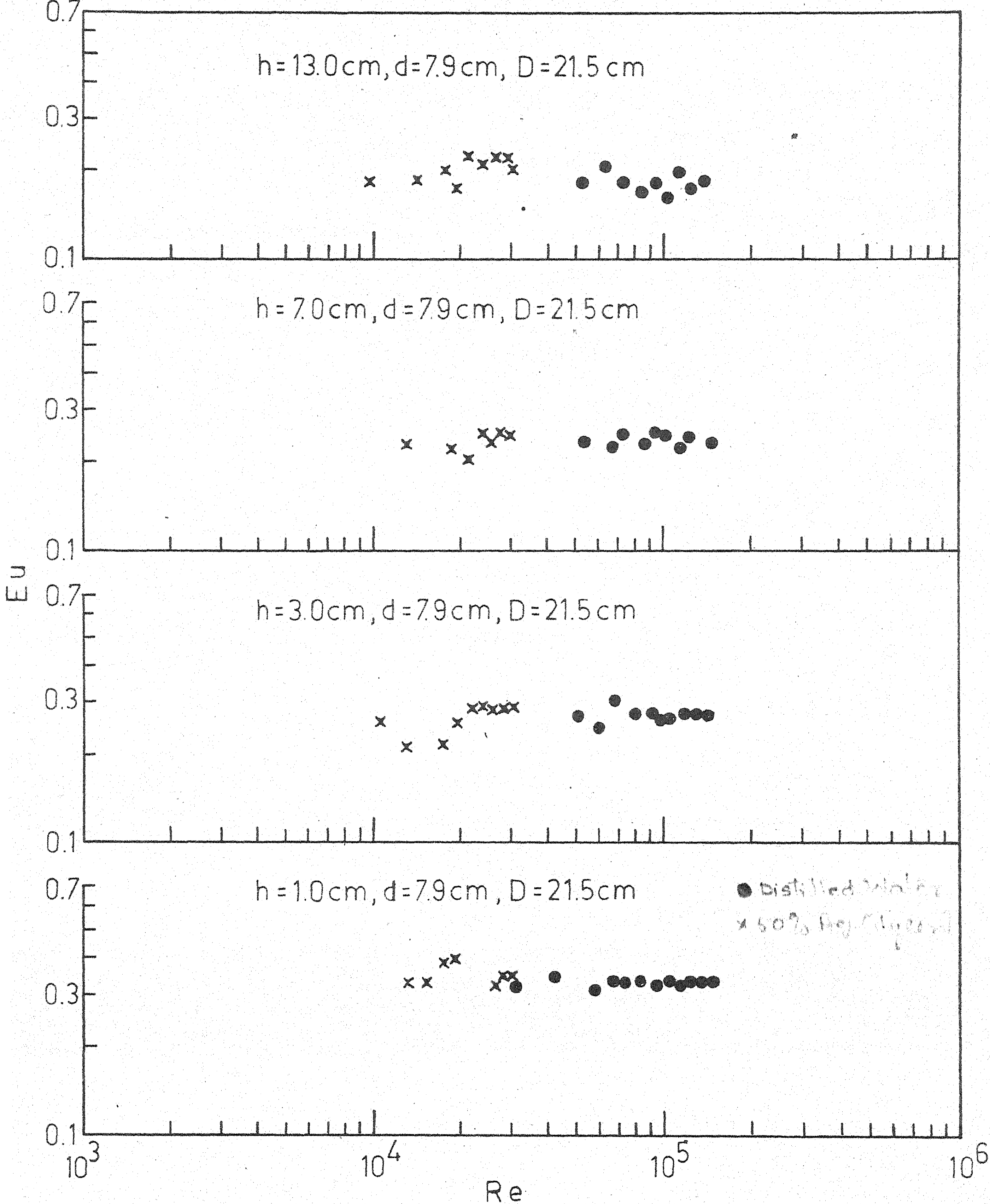


Fig. 13 -Dependence of Eu on Re cylindrical vessels with baffles by pressure profile.

where a,b, and c are exponents, which can be estimated from the experimental data. For the region Re$>10^4$ it was found out that Eulers number is independent of Reynolds number and hence considering this region i.e. Re$>10^4$, we can rewrite the equation (27) as

$$E_u = C(d/D)^b \ (h/D)^c \tag{35}$$

where C is a constant.

On plotting curves between Eulers number and h/D taking d/D as parameter (Figure 14) following trends can be identified:

8.2.1 On comparing curves P and Q or R and S, it can be observed that Eulers number decreases with increase in the propeller diameter. For example the tank diameter in the runs corresponding to curves P and Q is same yet the Eulers number as represented by curve Q are consistently lower than their counterpart values given by curve P. The only change in the flow configuration is that a bigger propeller has been used for Q. This suggests that Eulers number is a function of propeller diameter as mentioned.

8.2.2 The Eulers number decreases with increase in h/D ratio upto some critical value of h/D and thereafter it remains constant with increase in h/D ratio. This is evident from Figure 14, curves P, Q, R and S.

8.2.3 The critical value of h/D for smaller vessel is the same i.e. 0.2 irrespective of mixer dimensions. Thus, for

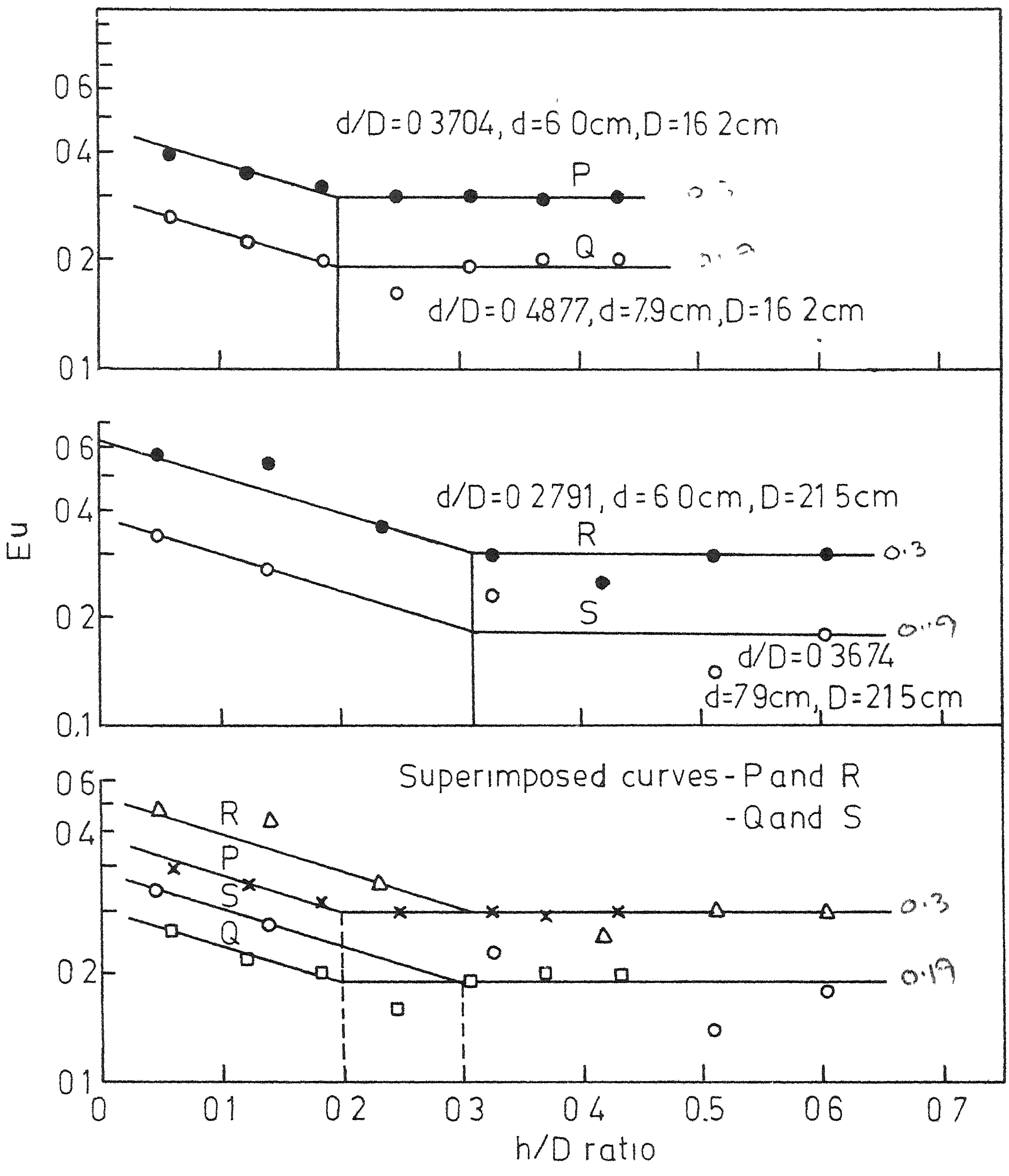


Fig 14 -Dependence of Eu on h/D ratio

curve P the tank diameter is 16.2 cm and the propeller diameter is 6.0 cm while for curve Q than tank diameter is the same but the propeller diameter is 7.9 cm., yet the value beyond which Eulers number remains constant occurs for both the curves at one value of h/D, which is 0.2. In the same way the critical value for curves R and S rest at h/D value of 0.3. In the latter case only the tank diameter has changed. It can be interpreted therefore that the critical value of h/D beyond which Eulers number remains constant depends on the tank diameter. Higher the vessel diameter, higher is the critical value of h/D.

8.2.4 If the curves P and R or Q and S are superimposed on each other as is done in Figure 14, it can be easily seen that beyond higher critical value of (h/D) the Eulers number remains same irrespective of the vessel diameter. Thus beyond h/D value equal to 0.3 which is the higher h/D critical value Eulers number remains constant at 0.3 for the same mixer dimensions although the tank diameter is different curves (P and Q). If the mixer dimension is changed same trend is observed but in this case the Eulers number records a constant value at 0.19. This stabilishes that beyond higher critical value of h/D, Eulers number is independent of vessel diameter D and depends on the mixer dimension d. That is

$$E_u = C\, d^{e_1} \tag{36}$$

$[h/D > (h/D)_{critical}$ and D is constant$]$

where C is a constant and e, is exponent.
The findings could not be extended to establish if d is involved in a dimensionless group because only two mixers of diameter 6.0 cm and 7.9 cm were available.

8.2.5 Below the critical value of h/D, the Eulers number depends on h/D as well as d/D. It can be seen that curves, P, Q, R and S in figure 14 representing a semilog plot, are straight lines parallel to each other. This suggests that Eulers number decays exponentially with increase of h/D that is

$$E_u = A_1 e^{-a(h/D)} \tag{37}$$

[$h/D < (h/D)_{critical} = 0.3$ and $d/D = 0.3674$]
The values of A_1 and 'a' can be evaluated from the plots to give the following relation:

$$E_u = 0.38\ e^{-2.4(h/D)} \tag{38}$$

The dependence of Eulers number on d/D can be found out by plotting Eulers number against d/D on a log-log plot taking h/D as parameter as shown in Figure 15.

$$E_u = A_2\ (d/D)^b \tag{39}$$

[$h/D < (h/D)_{critical}$ and constant $h/D = 0.05$]
The values of A_2 and b can be evaluated from the Figure 15, to give the following relation

$$E_u = 0.11\ (d/D)^{-1.23} \tag{40}$$

Finally, it can be written that below the critical value of h/D, the Eulers number depends upon d/D and h/D for the region

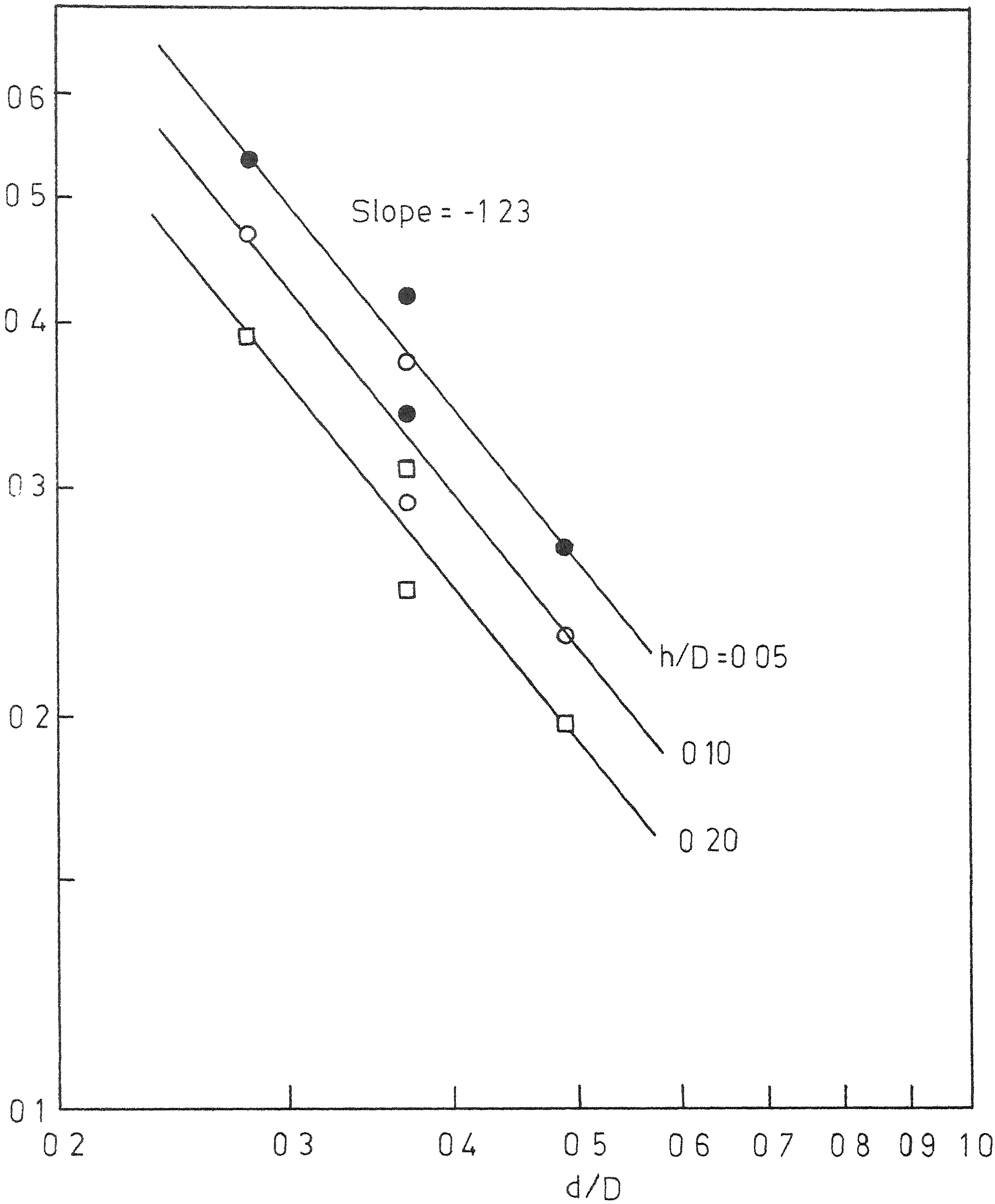


Fig 15 -Dependence of Eu on d/D ratio

$Re > 10^4$, Equation (35) can be written as

$$E_u = C(d/D)^{-1.23} \; e^{-2.4(h/D)} \tag{41}$$

where C is a constant and is function of h/D and d/D.

Fort, Eslamy and Kosina [8] found that Eulers number is a function of h/D and is independent of d/D as well as d, they found the equation

$$E_u = 0.173 \; (h/D)^{-0.39} \tag{42}$$

8.3 Dependence of $\frac{d_1^+}{D}$ on $\frac{h}{D}$, d/D and Re:

It was found that d_1^+ and d_2^+ depend upon h, the height of propeller from the base of the vessel for a given tank diameter. As the distance of the mixer from the base is increase h is increased, the d_1^+ value increases and d_2^+ value decreases and at one position of mixer d_1^+ becomes equal to d_2^+. In this case d_1^+ can be designated as $(d_1^+)_{max}$. At this condition the region of negative pressure at the vessel bottom disappears. It has been found that the ratio $(d_1^+)_{max}/D$ fluctuates from 0.66 to 0.74 as has been shown in Table 8.1, but in most of the cases it remains constant at 0.70. On taking the arithmetic mean of $(d_1^+)_{max}/D$, it comes out to be 0.707. Therefore we can have the relation

$$d_1^+ = 0.707 \; D = (d_1^+)_{max} \tag{43}$$
$$[\text{for } h = h_{max}]$$

Fort, Eslamy and Kosina [8] also have reported a similar limiting value of $d_1^+ = 0.707$ D for $h=h_{max}$. They have not given the dimensionless value of $(h/D)_{max}$ at which this equality hold From the present experiments also, because of limiting information it could not be done.

TABLE 8.1

$(d_1^+)_{max}/D$	.722[a]	.722[a]	.744[a]	.698[a]	.690[b]	.746[b]	.698[b]	.664[b]	.696[c]
d/D	.370	.488	.279	.367	.370	.488	.279	.367	.370

[a] Distilled water [b] 50 per cent Aq. Glycerol

[c] Mustard oil

The heightof propeller from the base of the vessel at $(d_1^+)_{max}$ corresponds to h_{max}. It can be interpreted from the tables given in Appendix VI, VII, and IX that below the h_{max} value d_1^+ depends upon the diameter of propeller d as well as diameter of vessel D which can be written by use of dimensional analysis as

$$\frac{d_1^+}{D} = C_1 \left(\frac{d}{D}\right)^b \left(\frac{h}{D}\right)^c \qquad (44)$$

$$\text{for } d_1^+ < (d_1^+)_{max}$$

where C_1 is a constant and b and c are exponents which can be evaluated from the curves by plotting d_1^+/D versus d/D taking h/D as constant and vice versa as shown in Figures 16 and 17. The calculated values of b and c are 0.42 and 0.27 respectively.

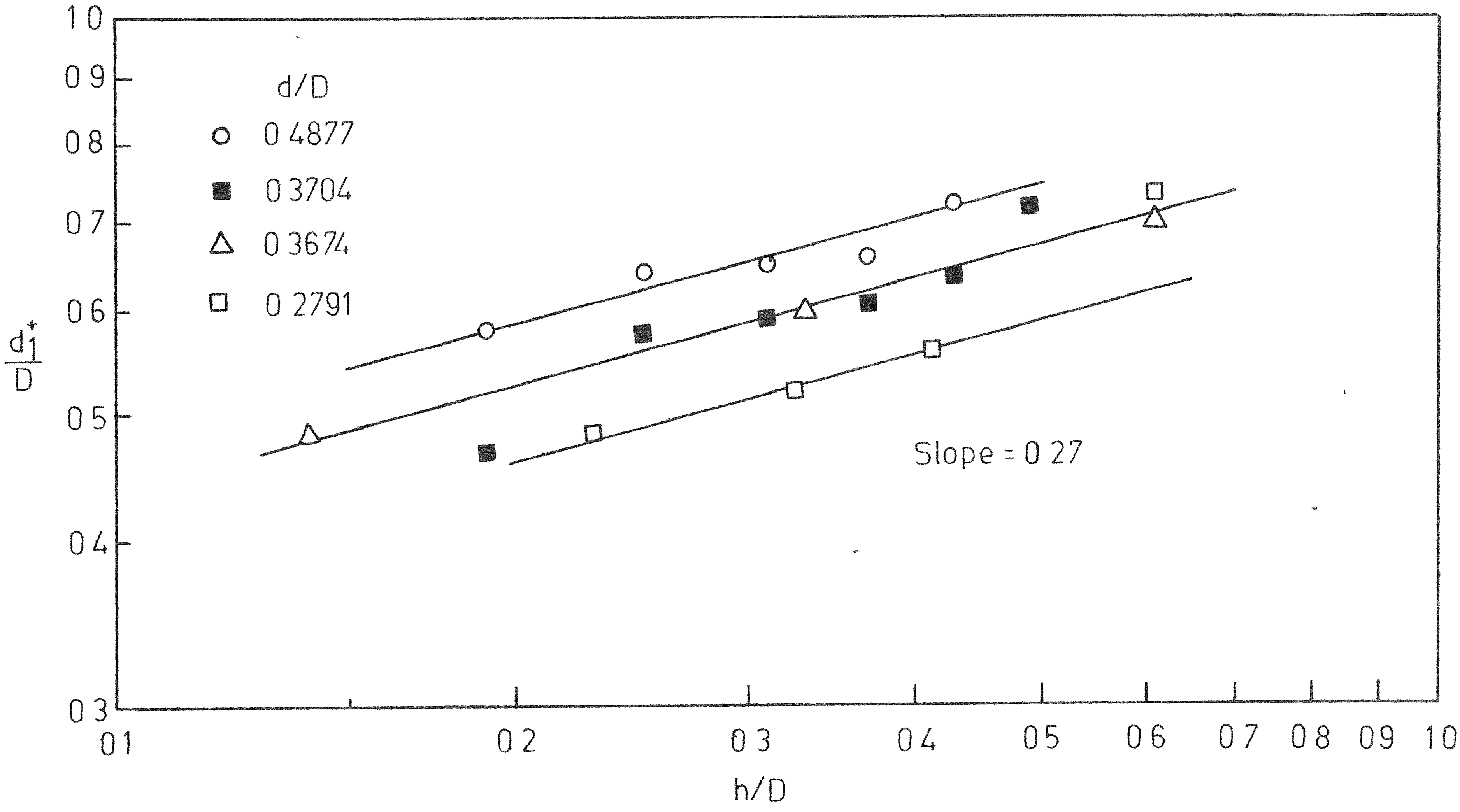


Fig 16 -Dependence of d_1^+/D on h/D ratio

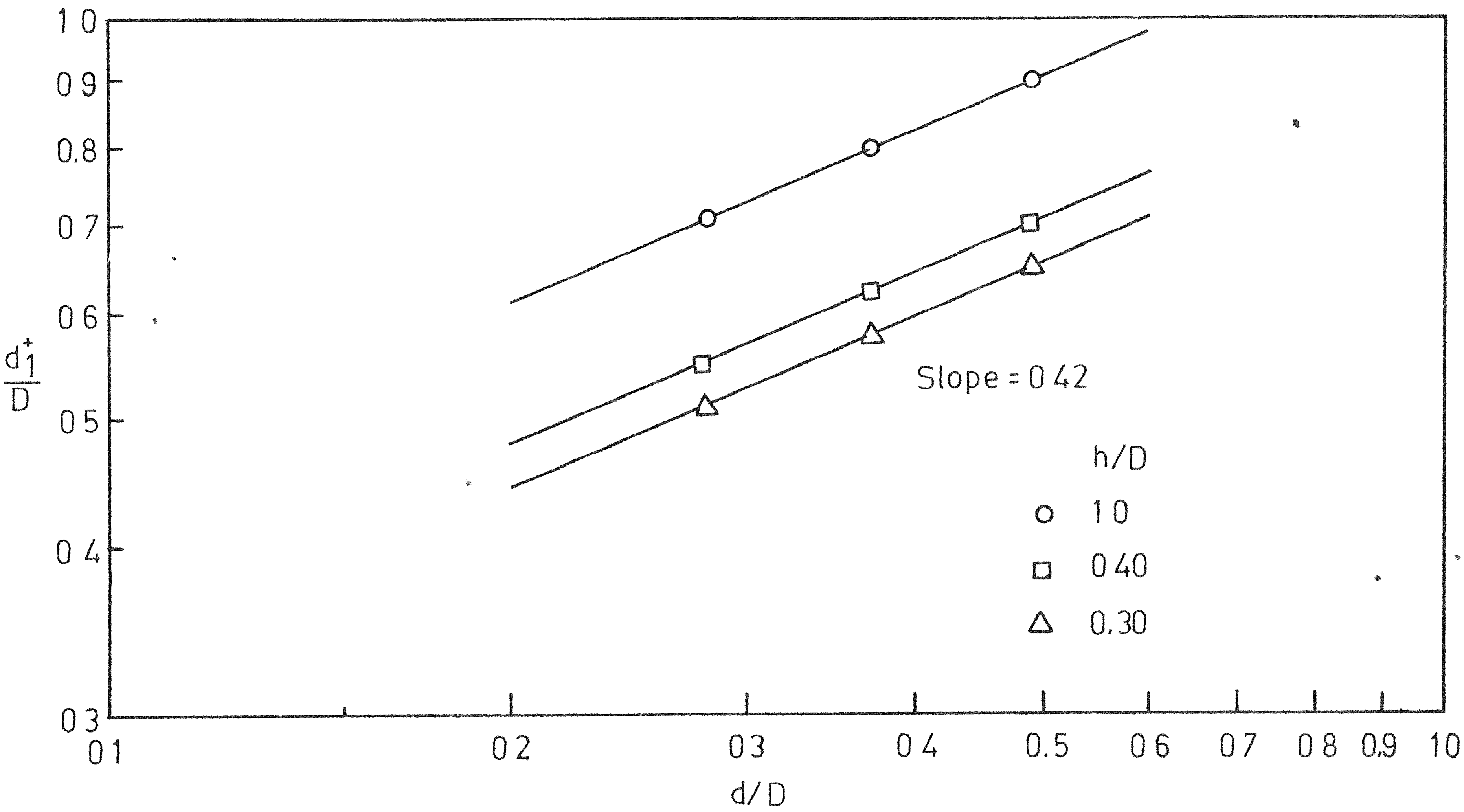


Fig 17 - Dependence of d_1^+ on d/D ratio

On substituting these values and evaluating the constant C_1 the final form of equation becomes

$$\frac{d_1^+}{D} = 1.25\ (d/D)^{0.42}\ (h/D)^{0.27} \quad \text{for } d_1^+ < d_{1\,max}^+ \tag{45}$$

It can be noted that the behaviour of d_1^+/D is below the critical value of $(h/D)_{max}$.

8.4 Dependence of K_{bt_1avg} on h/D, d/D and Re:

From the observations (Appendix VI to IX) obtained it was found that the values of K_{bt_1} and K_{bt_3} are considerably different when the propeller was kept close to the base of the vessel and the difference in K_{bt_1} and K_{bt_3} reduces as the propeller height from the base of the vessel increases. The K_{bt_1} value being more than K_{bt_3} at lower value of h means that it is due to entrainment of liquid from the surroundings. This amount of entrainment decreases till K_{bt_1} and K_{bt_3} becomes more or less same. The total flow rate at the vessel bottom V_{bt_1} is more than the total flow rate up along the vessel wall suggests that all the volume of the liquid does not flow up but short circuits and recirculates in the propeller surroundings to be pushed down by the propeller. However with the increased value of h/D, streamline pattern gradually so stabilizes that all the liquid pushed down by the propeller after flowing along the bottom flows up along the wall, under these conditions value

of K_{bt_1} decreases to approach the value of K_{bt_3}. It was also found that K_{bt_1} and K_{bt_3} values do not fluctuate much with change of the speed of the propeller for the region $Re > 10^4$.

By the help of dimensional analysis, it is possible to find out the dependence of K_{bt_1} on h/D and d/D for the regio $Re > 10^4$.

$$K_{bt_1} = C_2 \ Re^a \ (d/D)^b \ (h/D)^c \qquad (46)$$

where C_2 is a constant and a, b and c are exponents.

As has been mentioned above that the K_{bt_1} has no effect of speed in region $Re > 10^4$, the above equation i.e. 46 can be simplified to

$$K_{bt_1avg} = C_2' \ (d/D)^b (h/D)^c \qquad (47)$$

where K_{bt_1avg} = average value of K_{bt_1} at different speeds.

By plotting $K_{bt_1}avg$ against h/D taking d/D as parameter and K_{bt_1avg} against d/D taking h/D as parameter, the exponents b and c can be calculated. These plots are shown in Figure 18. The calculated values of b,c and C_2' are -0.188, -0.082 and 0.0948 respectively. On substituting these values in Eqn.(47) we get

$$K_{bt_1avg} = 0.0949 \ (d/D)^{-1.83} (h/D)^{-0.082} \qquad (48)$$

A practical extension in terms of a comparison of K_{bt_1avg} or the volumetric flow rate with the pumping capacity of the propeller generating this flow would be attempted, once the

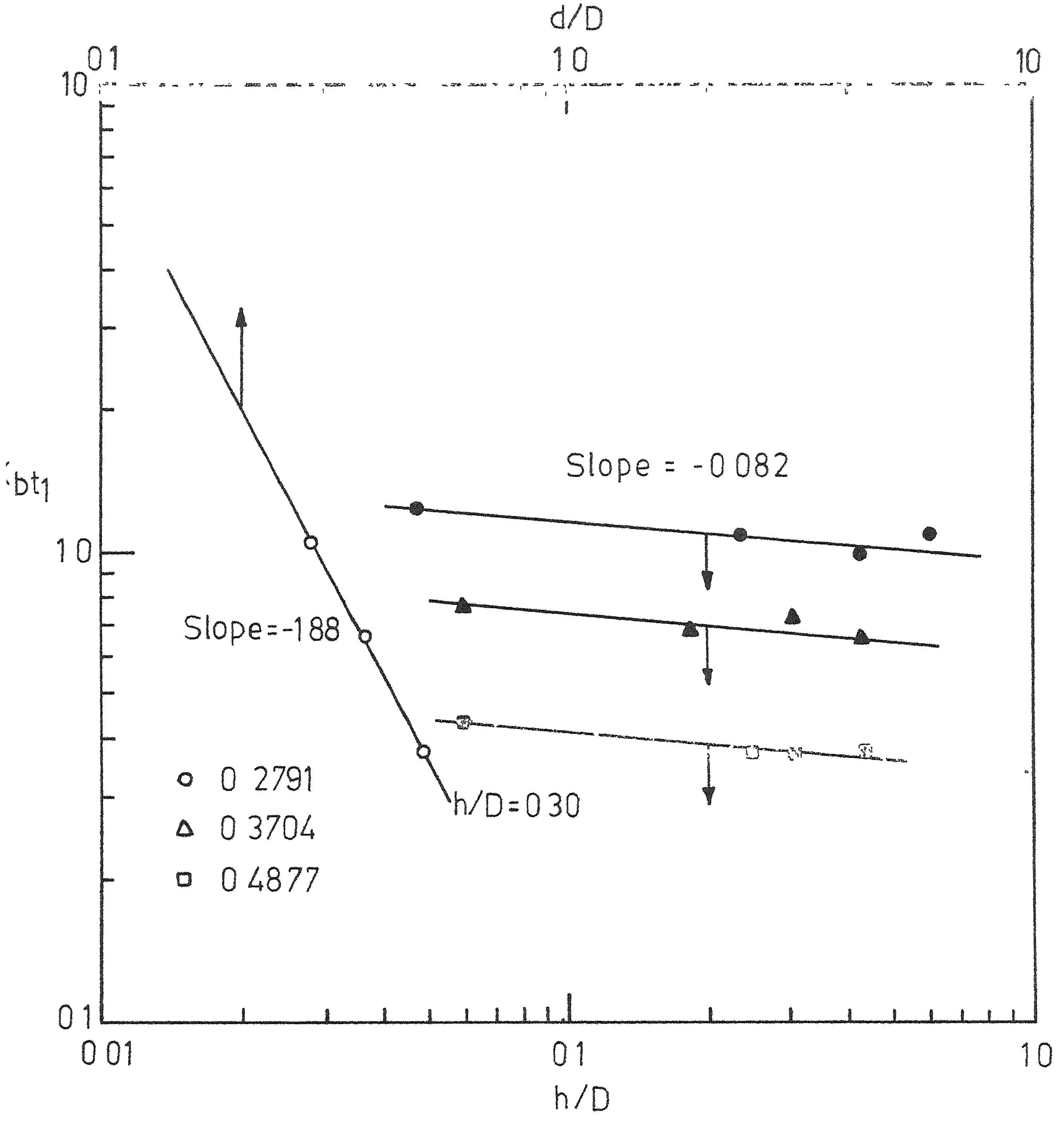


Fig 18 - Dependence of K_{bt_1} on h/D and d/D ratio

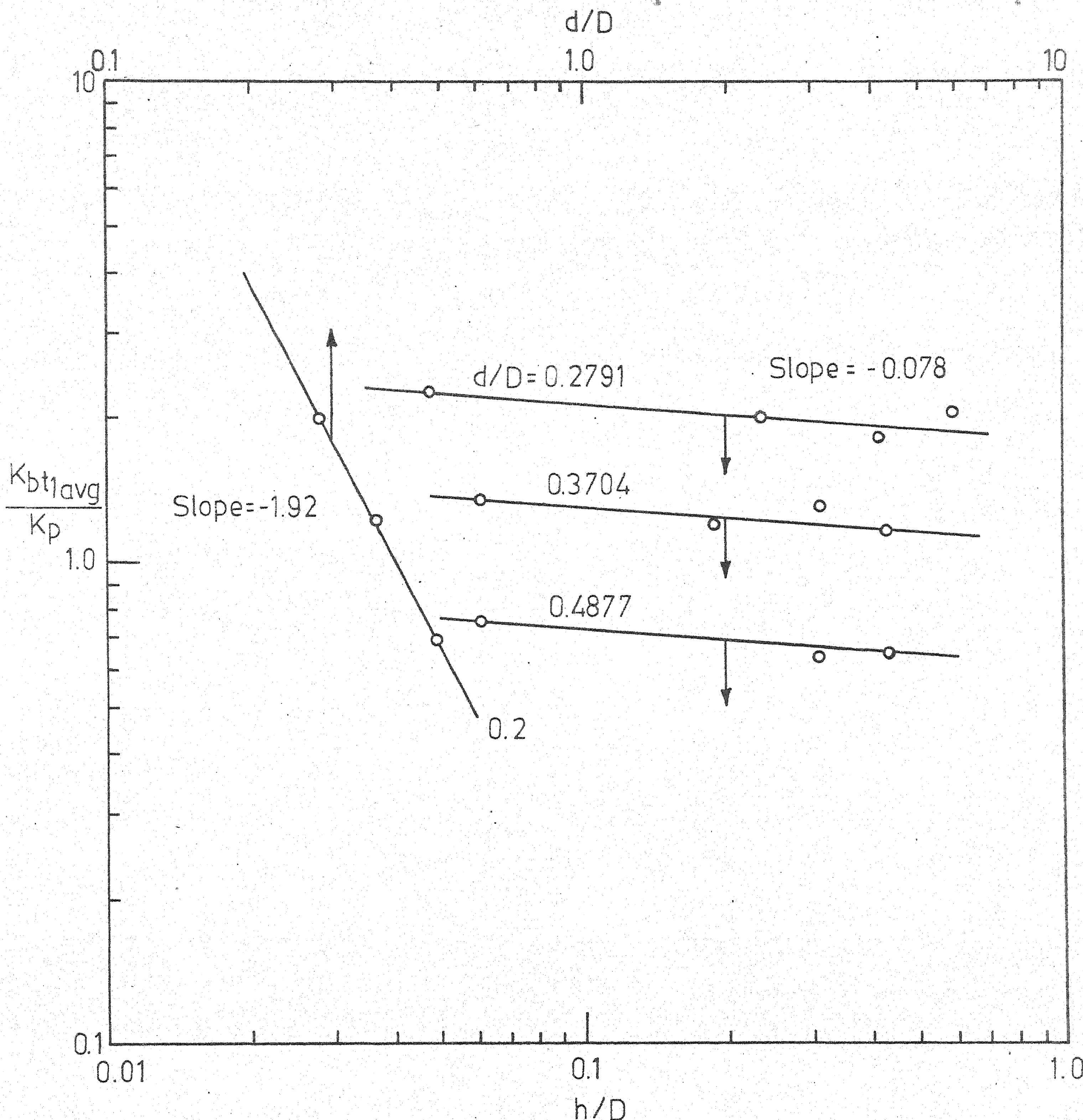


Fig. 19 - Dependence of $K_{bt_{1avg}}/K_p$ on d/D and h/D ratio.

It can be seen from the above equation that as h/D decreases k_{bt_1avg}/k_p increases. This obviously is due to entrainment from the surroundings of the propeller. As h/D ratio is increased the entrained liquid from the surrounding decreases and the ratio of K_{bt_1avg}/K_p decreases from Figure 19, it follows that the total flow rate at the vessel bottom may be smaller or larger than the volumetric mixer capacity in dependence on the actual geometrical conditions.of the system. The larger total flow rate at the vessel bottom than the volumetric capacity may be explained by the entrained or induced flow which results from the momentum transfer between the liquid flow streaming from the mixer blades and the medium surroundings it.

8.5 Equal Circulation of Fluid by Use of Draft Tube:

The essential condition for equal circulation rate of incompressible fluid which is coming from the propeller surroundings and then going up along the wall of the vessel, is to have equal flow area. In order to check the equal circulation of fluid, it was thought to use weighing procedure by rotating the propeller in clockwise and anticlockwise directions. On rotating the propeller in clockwise direction, the fluid moves towards the bottom of the vessel, which gives rise to increase in weight of the system. On the other hand, by rotating the propeller in anticlockwise direction, the fluid moves upwards to the surface of the liquid and then down along the walls which gives

rise to decrease in the weight of the system. There is a particular position for a given geometry of the system when the axial force acting downwards due to clockwise rotation of propeller becomes equal to the axial force acting onwards due to anticlockwise rotation of the propeller, gives the condition of equal circulation of fluid.

Draft tubes are usually used with axial impellers to direct central the suction/or discharge streams. In order to achieve and check the equal circulation rate of fluid, a draft tube could be used whose diameter was taken more than the propeller diameter and less than the vessel diameter. Let us assume a draft tube of diameter d_d, which can give equal circulation of fluid. When control tubular area (flow towards the bottom at the plane of the propeller) was made equal to the annular area (flow along the walls), flow following expression was obtained:

$$\frac{\pi}{4} (d_d)^2 = \frac{\pi}{4} (D^2 - d_d^2) \qquad (52)$$

or $$d_d = D/\sqrt{2}$$

The height of the draft tube h_d from the base of the vessel can also be calculated from the following equation

$$2\pi \frac{d_d}{2} h_d = \frac{\pi}{4} d_d^2 \qquad (53)$$

or $$h_d = \frac{d_d}{4} = \frac{D}{4\sqrt{2}}$$

When the draft tube was kept 1 cm from the base of the

vessel, it was noticed that in no case equal circulation was possible what-so-ever be the height of the propeller from the base of the vessel. This is evident from Figure 20. On increasing the height of the draft tube to 2.9 cm which corresponds to $D/4\sqrt{2}$, it was noticed that at h=7.0 cm equal circulation of the fluid occurred. This is shown in Figure 21. In this case the increase and decrease in the weights of the system by rotating the propeller clockwise and anticlockwise directions, are the same.

When the height of the draft tube was further increases to 4.10 cm from the base of the vessel, it was found that at small values of h, the increased weight of the system was more than the decreased weight of the vessel. This situation occurred till h=5.0 cm and on further increase of h, the increased weight of the vessel was found to be less than the decreased weight of the vessel, when the propeller was rotated in clockwise and anticlockwise directions respectively. This is shown in Figure 22. This equality of the weights occurred at a propeller height of h=8.5 cm. On further increase of the draft tube height at 5.3 cm from the base of the vessel, it was seen that in no case equal circulation was possible what-so-ever be the height of the propeller from the base of the vessel. This can be seen from Figure 23.

From all these findings it can be concluded that there is a small region for the height of the draft tube and

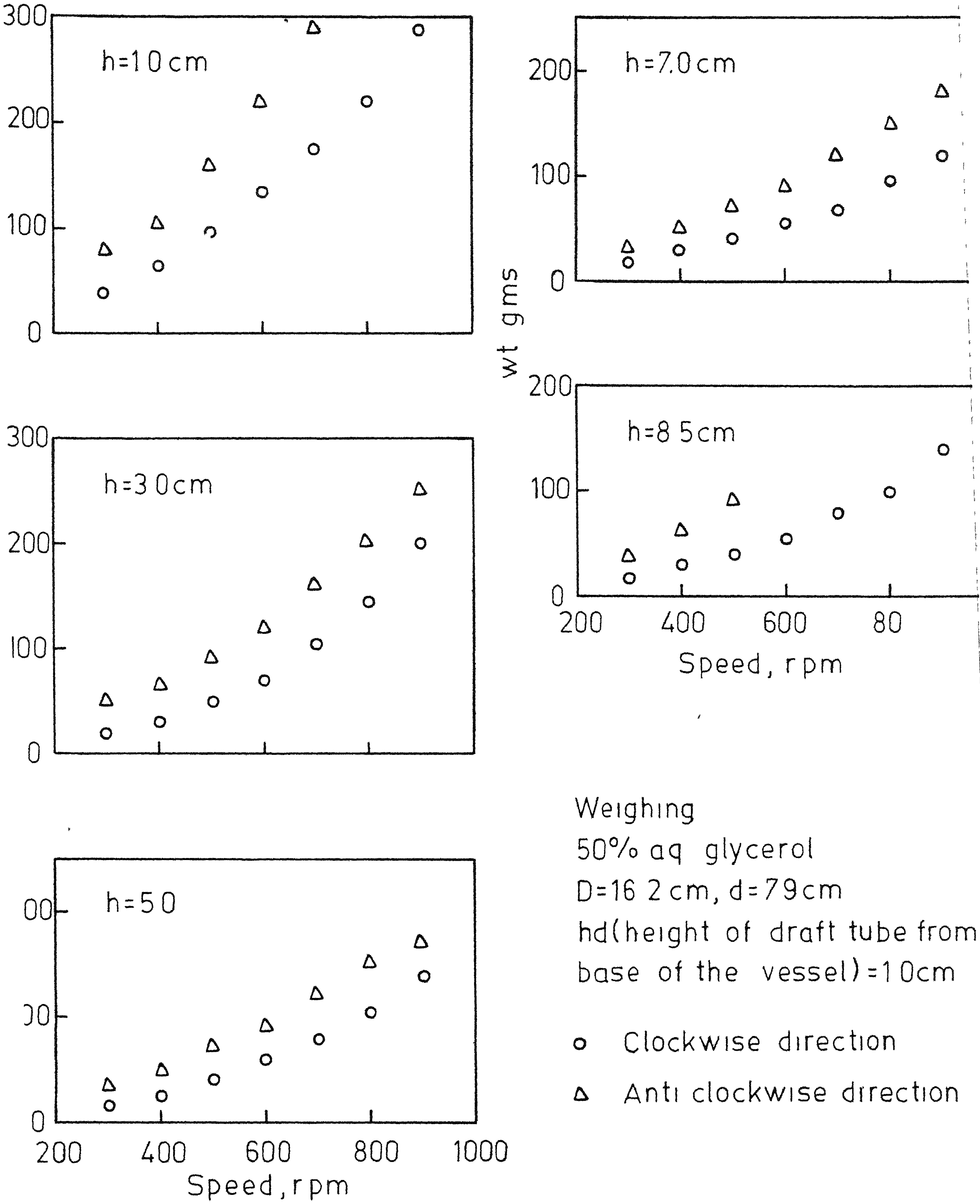
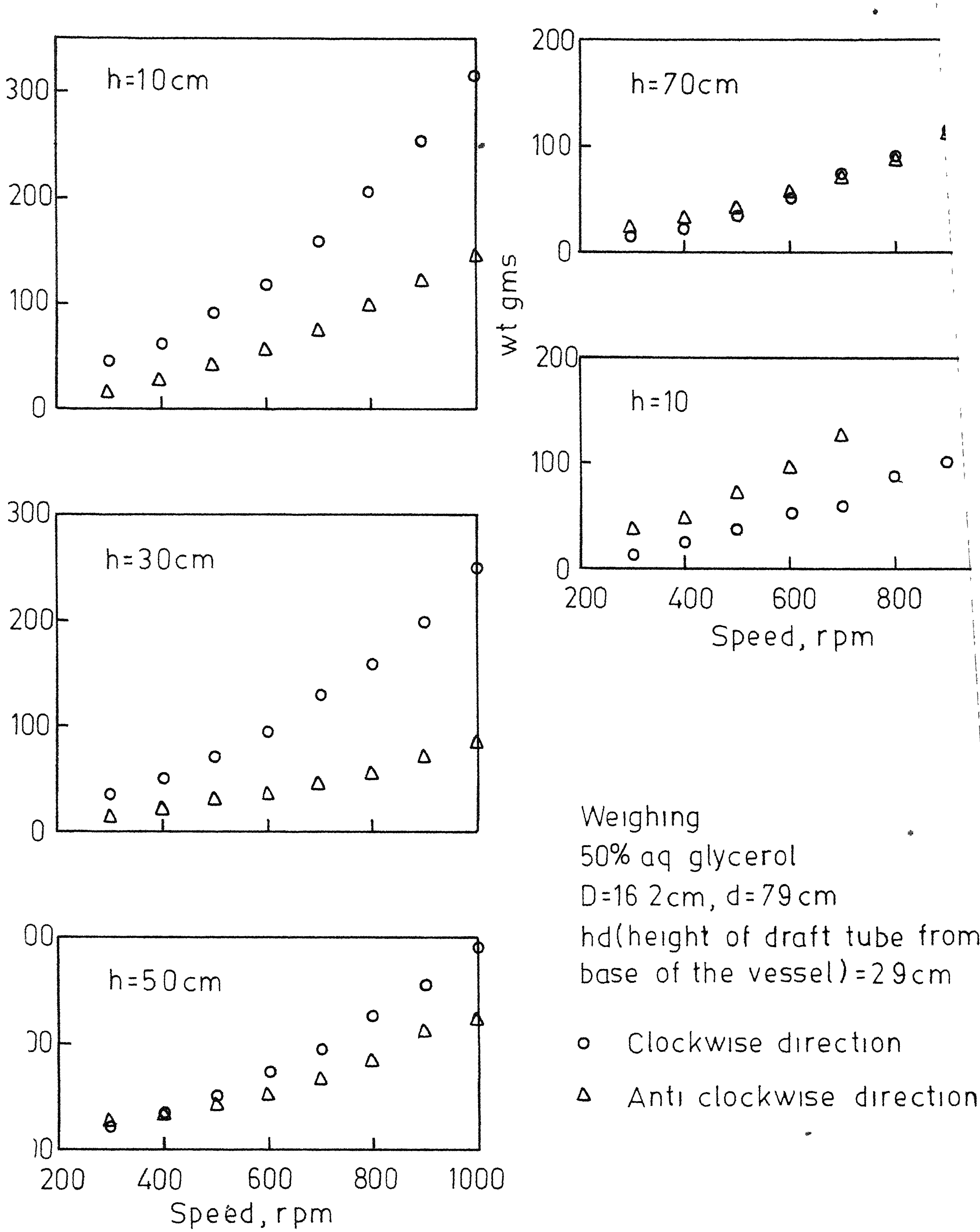


Fig 20 - Dependence of change in the weight of the vessel



ig 21 - Dependence of change in the weight of vessel versus speed

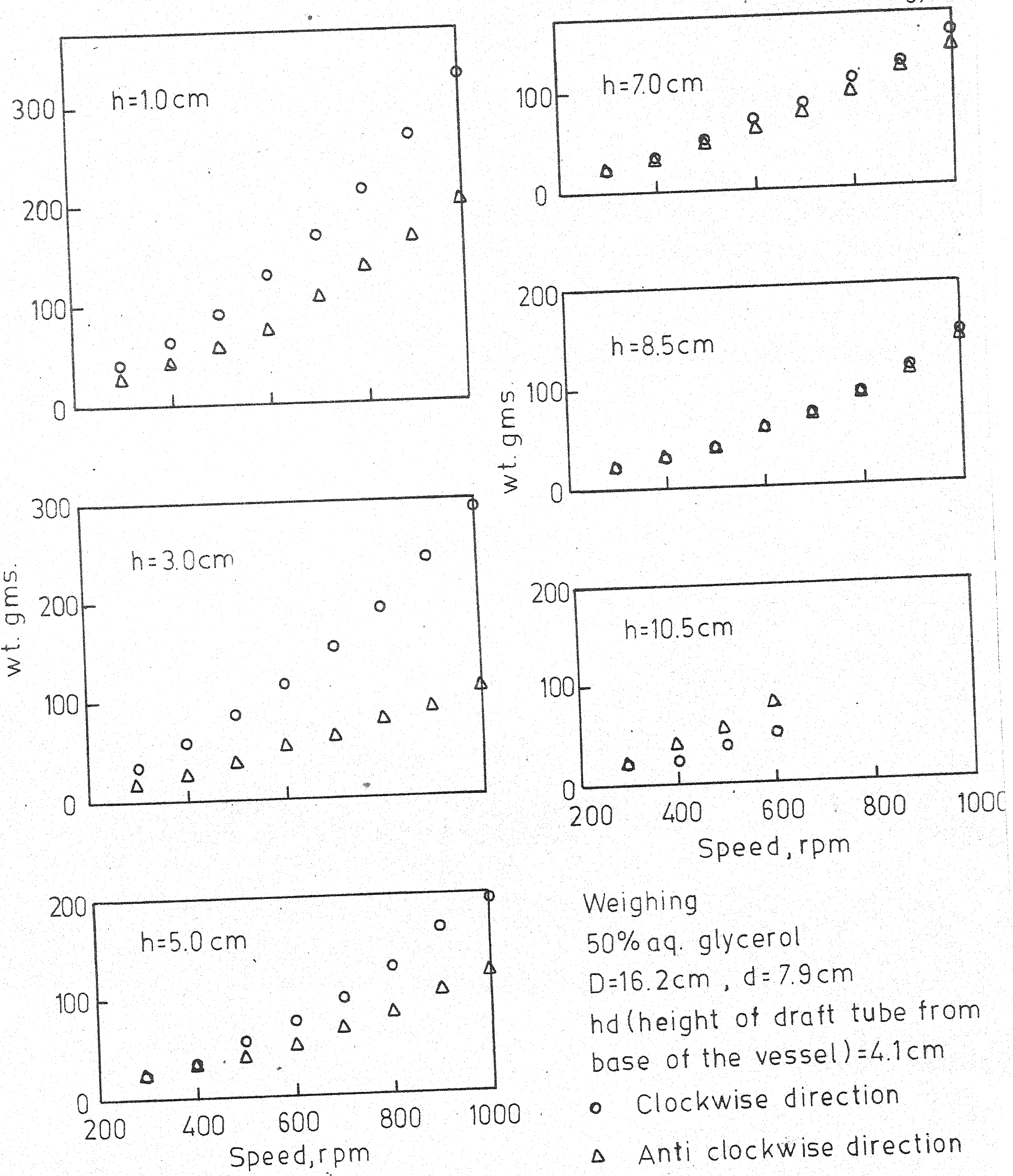


Fig. 22 - Dependence of change in the weight of the vessel vesus speed.

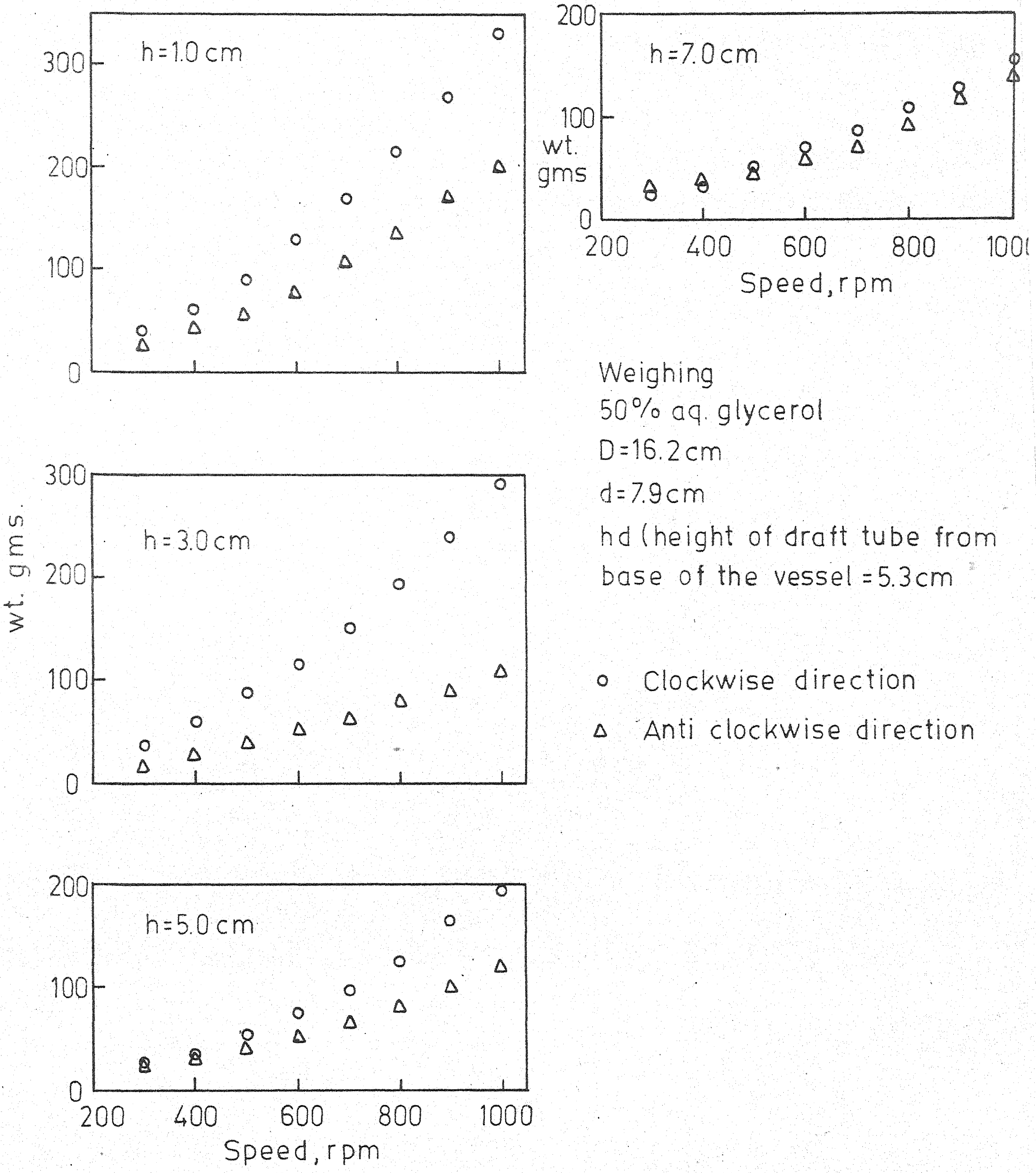


Fig. 23 - Dependence of change in the weight of vessel versus speed.

correspondingly the height of the propeller which gives equal circulation of fluid. The region of draft tube height from the vessel bottom is near $D/4\sqrt{2}$ and corresponding propelle height around 0.5 D which gives equal flow of the fluid.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

In the present work different fluids were stirred by a marine propeller in a flat bottom cylindrical tank, and following conclusions were drawn:

1. Of the two ways for measuring the Eulers number, one by measuring the pressure distribution over the bottom of the vessel and the other by weighing the vessel, it was observed that the weighing procedure is more reliable and accurate than the pressure distribution measurement procedure. By weighing one can take the observations at a very low speed of propeller of about 50 rpm and thus one can reach to lower Reynolds number which is not possible by pressure measurements.

2. The Eulers number was found to be constant in the region $Re > 1.0 \times 10^4$ and below the region $Re < 10^4$ its value decreases. Its value decreases with increase of the propeller height from the base of the vessel upto some critical height, which depends upon the diameter of the vessel and thereafter the value remains constant with the increase in the propeller diameter, the Eulers number value decreases.

3. With the increase of the propeller height from the base of the vessel, d_1^+ increases and d_2^+ decreases and at one particular position both of these values i.e. d_1^+ and d_2^+ become equal which corresponds to 0.707D.

4. At lower height of the propeller from the base of the vessel, K_{bt_1} was found to be more than K_{bt_3} and as the height of the propeller was increased, both the values i.e. K_{bt_1} and K_{bt_3} become the same. The volume of the liquid transported by the propeller to the base of the vessel may be more or less than the pumping capacity of the propeller depends upon the geometrical conditions.

5. When a draft tube of given diameter, equal to $D/\sqrt{2}$, was placed at a particular height, equal to $D/4\sqrt{2}$ from the base of the vessel it was found that at certain height of propeller, which is near 0.5D, equal circulation of fluid occurs.

Recommendations:

The study should be extended to generate more data with different dimensions of mixers to stablish the effects of h/D and also with different types of axial and radial mixers. It would be interesting to repeat the work by weighing procedure in laminar range i.e. Re $<$ 100.

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APPENDIX I

CHARACTERISTICS OF MIXED SYSTEM

	Physical Properties[a]	
Charge	Density gms/cc	Viscosity, cp
Distilled water	1.0000	0.9820
50 per cent Aqueous Solution of Glycerol	1.1463	5.4375
60 per cent Aqueous Solution of Glycerol	1.1933	22.1053
Mustard Oil	0.9191	62.8968

[a]Conditions at both series of experiments: axial force component measurements by weighing and axial pressure distribution measurements on the vessel bottom

Geometry					
D cm	d cm	d/D	h cm	h/D	Range of rotational speed of propeller 1/min
16.2[a]	6.0	0.3704	1.0	0.062	300 - 1700
16.2[a]	6.0	0.3704	3.0	0.185	300 - 1700
16.2[a]	6.0	0.3704	5.0	0.309	300 - 1600
16.2[a]	6.0	0.3704	7.0	0.432	300 - 1600
16.2[a]	7.9	0.4877	1.0	0.062	200 - 1500
16.2[a]	7.9	0.4877	3.0	0.185	200 - 1600
16.2[a]	7.9	0.4877	5.0	0.309	150 - 1600
16.2[a]	7.9	0.4877	7.0	0.432	150 - 1600
21.5[b]	6.0	0.2791	5.0	0.233	500 - 1400
21.5[b]	6.0	0.2791	7.0	0.326	550 - 1500
21.5[b]	6.0	0.2791	9.0	0.419	750 - 1500
21.5[b]	6.0	0.2791	13.0	0.605	600 - 1500
21.5[b]	7.9	0.3674	1.0	0.047	300 - 1400
21.5[b]	7.9	0.3674	3.0	0.140	500 - 1400
21.5[b]	7.9	0.3674	7.0	0.326	520 - 1400
21.5[b]	7.9	0.3674	13.0	0.605	450 - 1400

[a] Conditions at both series of experiments: axial force component measurements by weighing and axial pressure distribution measurements on the vessel bottom

[b] Conditions at the axial pressure distribution measurements on the vessel bottom.

APPENDIX II

DISTILLED WATER DATA

$h = 1.0$ cm
$d = 6.0$ cm
$D = 16.2$ cm

Speed in rpm
Pressure (Pr) in cm of distilled water
Radius in cm

Run 1 Speed	650	775	800	900	1000	1100	1200	1300	1400	1500
Radius	Pr	Pr	Pr	Pr	Pr	Pr	Pr	Pr	Pr	Pr
0.00	1.15	1.50	1.90	2.25	2.90	3.30	4.25	5.00	5.77	6.60
0.65	1.20	1.50	1.90	2.25	2.90	3.30	4.25	5.00	5.77	6.60
1.30	1.35	1.95	2.10	2.60	3.25	3.53	4.95	5.80	6.60	7.10
1.95	1.95	2.70	2.75	3.60	4.50	4.90	6.65	7.90	9.00	10.30
2.60	2.00	2.75	2.90	3.85	4.80	5.50	7.05	8.60	9.80	11.20
3.25	1.10	1.55	1.60	2.30	2.85	3.30	4.05	5.07	5.80	6.33
3.90	0.20	0.20	0.25	0.30	0.50	0.53	0.50	0.50	0.60	0.60
4.55	-0.10	-0.10	-0.20	-0.35	-0.35	-0.40	-0.55	-0.70	-0.87	-1.10
5.20	-0.20	-0.20	-0.30	-0.50	-0.60	-0.70	-1.05	-1.23	-1.53	-1.87
5.85	-0.20	-0.20	-0.30	-0.50	-0.55	-0.66	-1.15	-1.23	-1.50	-1.80
6.50	-0.10	-0.10	-0.10	-0.25	-0.25	-0.40	-0.40	-0.43	-0.50	-0.70
7.15	0.30	0.60	0.60	0.70	0.95	1.11	1.22	1.50	1.77	1.93
7.80	0.60	1.00	1.20	1.40	1.80	2.13	2.30	2.50	3.50	3.97

h = 3.0 cm

d = 6.0 cm

D = 16.2 cm

Run 2

Speed / Radius	450 Pr	500 Pr	600 Pr	700 Pr	800 Pr
0.00	0.70	1.00	1.00	1.80	2.20
0.65	0.70	1.00	1.20	2.00	2.50
1.30	0.70	1.00	1.80	2.60	3.10
1.95	0.50	1.00	1.60	2.70	3.30
2.60	0.40	0.70	1.10	1.90	2.50
3.25	0.30	0.40	0.50	0.90	1.00
3.90	-0.10	-0.10	-0.10	-0.40	-0.50
4.55	-0.20	-0.30	-0.30	-0.70	-0.90
5.20	-0.20	-0.30	-0.30	-0.90	-1.00
5.85	-0.20	-0.40	-0.40	-0.80	-0.90
6.50	-0.20	-0.20	-0.20	-0.50	-0.60
7.15	0.30	0.40	0.40	0.70	0.80
7.80	0.40	0.60	0.60	1.10	1.50

$h = 5.0$ cm ; $d = 6.0$ cm ; $D = 16.2$ cm

RUN 3

Speed / Radius	700 Pr	800 Pr	950 Pr	1050 Pr	1150 Pr	1230 Pr	1300 Pr	1400 Pr	1500 Pr
0.00	0.90	1.00	1.50	1.90	2.30	2.40	2.50	2.70	2.90
1.30	1.00	1.15	1.65	2.30	2.60	2.70	3.50	3.40	4.26
2.60	1.20	1.50	2.20	3.00	3.30	3.40	4.10	4.42	6.00
3.90	0.40	0.60	0.71	0.81	0.90	1.24	1.30	1.60	1.75
5.20	-0.12	-0.20	-0.30	-0.53	-0.50	-0.55	-0.70	-0.70	-1.10
6.50	0.05	0.15	0.20	0.30	0.20	0.20	0.20	0.20	0.20
7.80	0.60	0.68	1.08	1.30	1.70	1.90	2.20	2.70	3.20

$h = 7.0$ cm ; $d = 6.0$ cm ; $D = 16.2$ cm

RUN 4

Speed / Radius	650 Pr	750 Pr	840 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr	1400 Pr	1500 Pr
0.00	0.30	0.30	0.50	0.60	0.70	0.83	1.00	1.15	1.40	1.60
1.30	0.40	0.41	0.68	0.75	1.17	1.11	1.52	2.10	2.30	2.50
2.60	0.60	0.77	0.97	1.23	1.68	1.85	2.35	3.10	3.30	3.50
3.90	0.40	0.50	0.55	0.70	0.75	0.96	1.05	1.25	1.55	1.77
5.20	-0.10	-0.10	-0.10	-0.10	-0.20	-0.20	-0.20	-0.30	-0.40	-0.40
6.50	0.15	0.20	0.30	0.30	0.40	0.40	0.40	0.50	0.50	0.70
7.80	0.45	0.63	0.80	1.00	1.10	1.63	1.80	2.20	2.55	2.75

h = 1.0 cm ; d = 7.9 cm ; D = 16.2 cm

RUN 5

Speed / Radius	400 Pr	500 Pr	700 Pr	800 Pr	1000 Pr
0.00	0.50	0.80	1.15	1.35	2.70
1.30	0.60	1.00	1.40	1.85	3.50
2.60	0.80	1.40	2.10	2.70	5.40
3.90	0.30	0.50	0.75	1.00	2.00
5.20	0.00	-0.10	-0.10	-0.15	-0.20
6.50	0.00	0.00	0.10	0.20	-0.75
7.80	0.25	0.55	0.90	1.25	2.60

h = 3.0 cm ; d = 7.9 cm ; D = 16.2 cm

RUN 6

Speed / Radius	500 Pr	600 Pr	700 Pr	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr
0.00	0.50	0.80	1.10	1.35	1.80	2.00	2.50	2.90
1.30	0.70	1.20	1.50	1.75	2.20	2.50	3.20	3.50
2.60	0.90	1.50	2.00	2.50	3.10	3.70	4.50	4.85
3.90	0.35	0.70	0.75	0.80	1.05	1.50	1.70	2.15
5.20	0.00	-0.25	-0.30	-0.50	-0.65	-0.70	-0.80	-1.00
6.50	0.00	-0.30	-0.30	-0.40	-0.40	-0.40	-0.50	-0.50
7.80	0.40	0.50	0.80	1.00	1.70	1.90	2.80	2.90

h = 5.0 cm ; d = 7.9 cm ; D = 16.2 cm

RUN 7

Speed / Radius	470 Pr	600 Pr	650 Pr	700 Pr	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr
0.00	0.40	0.60	0.70	0.90	1.10	1.40	1.70	2.20	2.45	3.00
1.30	0.40	0.60	1.00	1.00	1.20	1.55	2.20	2.60	3.35	3.80
2.60	0.30	0.80	1.35	1.20	1.50	2.10	2.80	3.10	4.00	4.45
3.90	0.30	0.50	0.50	0.60	0.80	1.00	1.00	1.40	1.70	1.85
5.20	0.00	0.00	0.00	-0.10	-0.10	-0.10	-0.10	-0.10	-0.30	-0.37
6.50	0.00	0.00	0.00	0.10	0.20	0.20	0.20	0.20	0.20	0.40
7.80	0.35	0.60	0.70	1.00	1.30	1.55	2.00	2.30	2.80	3.40

h = 7.0 cm ; d = 7.9 cm ; D = 16.2 cm

RUN 8

Speed / Radius	460 Pr	550 Pr	650 Pr	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr
0.00	0.25	0.25	0.40	0.60	0.80	0.90	1.20	1.40	1.60
1.30	0.30	0.30	0.60	0.90	1.10	1.30	1.50	2.10	2.50
2.60	0.45	0.45	0.80	1.20	1.40	1.80	1.95	2.50	3.40
3.90	0.20	0.30	0.50	0.70	0.70	1.10	1.20	1.50	1.70
5.20	0.05	0.10	0.10	0.15	0.15	0.20	0.20	0.25	0.30
6.50	0.10	0.25	0.35	0.40	0.50	0.50	0.70	0.90	0.95
7.80	0.40	0.70	0.90	1.35	1.50	1.90	2.35	2.80	3.30

h = 5.0 cm ; d = 6.0 cm ; D = 21.5 cm

RUN 9

Speed / Radius	$\frac{600}{Pr}$	$\frac{830}{Pr}$	$\frac{1050}{Pr}$	$\frac{1100}{Pr}$	$\frac{1200}{Pr}$	$\frac{1400}{Pr}$
0.00	0.90	1.20	2.10	3.10	3.50	4.30
2.00	1.60	2.10	3.80	4.60	5.50	7.90
4.00	0.60	1.10	1.80	2.60	2.90	3.80
6.00	-0.20	-0.20	-0.20	-0.50	-0.50	-0.70
8.00	-0.20	-0.30	-0.40	-0.80	-1.00	-1.10
10.00	0.30	0.50	0.60	0.90	0.90	1.50

h = 7.0 cm ; d = 6.0 cm ; D = 21.5 cm

RUN 10

Speed / Radius	$\frac{550}{Pr}$	$\frac{680}{Pr}$	$\frac{700}{Pr}$	$\frac{800}{Pr}$	$\frac{900}{Pr}$	$\frac{1050}{Pr}$	$\frac{1200}{Pr}$	$\frac{1300}{Pr}$	$\frac{1400}{Pr}$	$\frac{1500}{Pr}$
0.00	0.20	0.40	0.60	1.00	1.30	1.40	1.80	2.00	2.20	2.80
2.00	0.50	1.10	1.40	1.50	2.20	2.80	4.00	4.20	4.50	5.00
4.00	0.30	0.70	0.70	1.10	1.10	1.70	2.30	2.70	3.50	3.90
6.00	0.00	0.00	-0.20	-0.20	-0.20	-0.20	-0.30	-0.50	-0.50	-0.60
8.00	-0.10	-0.10	-0.20	-0.20	-0.40	-0.40	-0.50	-0.60	-0.90	-1.10
10.00	0.20	0.20	0.20	0.40	0.40	0.70	1.00	1.00	1.10	1.20

h = 9.0 cm ; d = 6.0 cm ; D = 21.5 cm

RUN 11

Speed / Radius	750 Pr	800 Pr	900 Pr	1000 Pr	1100 Pr	1300 Pr	1400 Pr
0.00	0.50	0.50	0.70	0.90	1.00	1.60	1.90
2.00	0.60	0.80	1.50	1.50	2.30	3.20	4.70
4.00	0.80	0.80	1.30	1.40	1.80	2.40	2.60
6.00	0.00	-0.10	0.00	-0.10	-0.10	-0.30	-0.40
8.00	0.00	-0.20	-0.20	-0.40	-0.50	-0.50	-0.90
10.00	0.30	0.30	0.50	0.50	0.60	0.80	1.00

h = 13.0 cm ; d = 6.0 cm ; D = 21.5 cm

RUN 12

Speed / Radius	600 Pr	780 Pr	900 Pr	1100 Pr	1400 Pr	1500 Pr
0.00	0.20	0.40	0.50	0.80	1.10	1.90
2.00	0.30	0.50	0.50	0.90	1.70	2.10
4.00	0.30	0.60	0.60	1.10	1.70	2.20
6.00	0.20	0.30	0.30	0.30	0.40	0.50
8.00	0.00	0.00	0.00	0.00	0.00	0.00
10.00	0.30	0.30	0.60	1.00	1.20	1.50

RUN 13 h = 1.0 cm ; d = 7.9 cm ; D = 21.5 cm

Speed / Radius	300 Pr	400 Pr	550 Pr	650 Pr	700 Pr	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr	1
0.00	0.40	0.70	1.30	1.60	2.20	2.90	3.30	4.10	5.20	6.10	7.20	8
2.00	0.80	1.20	2.10	2.60	3.50	4.70	5.20	6.80	8.80	9.50	11.70	14
4.00	0.40	0.70	1.20	1.70	2.10	2.90	3.30	4.50	5.30	6.50	7.70	8
6.00	-0.10	-0.10	-0.20	-0.20	-0.30	-0.60	-0.70	-0.70	-1.00	-1.00	-1.20	-1
8.00	-0.10	-0.10	-0.20	-0.20	-0.40	-0.60	-0.70	-0.80	-1.10	-1.30	-1.40	-1.
10.00	0.20	0.30	0.60	0.80	1.00	1.30	1.60	2.10	2.50	2.80	3.30	3.

RUN 14 h = 3.0 cm ; d = 7.9 cm ; D = 21.5 cm

Speed / Radius	500 Pr	570 Pr	650 Pr	770 Pr	880 Pr	950 Pr	1050 Pr	1150 Pr	1250 Pr	1350 Pr
0.00	0.80	1.00	1.70	2.00	2.40	3.05	3.60	4.50	5.30	6.00
2.00	1.40	1.80	2.70	4.00	4.50	5.00	5.67	8.40	8.00	9.40
4.00	1.00	1.20	1.70	2.40	2.90	3.80	4.70	5.30	6.70	7.30
6.00	-0.20	-0.40	-0.40	-0.50	-0.50	-0.65	-0.90	-1.10	-1.13	-1.25
8.00	-0.20	-0.30	-0.40	-0.50	-0.60	-0.80	-1.00	-1.30	-1.40	-1.60
10.00	0.50	0.70	9.90	1.20	1.50	1.95	2.30	2.80	3.20	3.70

h = 7.0 cm ; d = 7.9 cm ; D = 21.5 cm

RUN 15

Speed / Radius	520 Pr	650 Pr	700 Pr	850 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1400 Pr
0.00	0.70	0.80	0.80	1.30	1.60	2.00	2.00	3.00	3.20
2.00	1.00	1.30	1.30	1.70	2.70	3.00	3.70	4.70	5.90
4.00	0.60	1.10	1.50	2.00	2.10	3.00	3.00	4.10	5.40
6.00	0.20	0.20	0.20	0.30	0.40	0.50	0.50	0.50	0.75
8.00	-0.10	-0.10	-0.20	-0.20	-0.40	-0.50	-0.80	-0.80	-0.90
10.00	0.40	0.50	0.70	0.90	1.10	1.50	1.80	2.00	2.50

H = 13.0 cm ; d = 7.9 cm ; D = 21.5 cm

RUN 16

Speed / Radius	500 Pr	600 Pr	700 Pr	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr
0.00	0.30	0.60	0.70	1.10	1.40	1.60	2.00	2.30	2.90
2.00	0.50	0.60	0.80	1.10	1.50	1.60	2.10	2.30	3.00
4.00	0.20	0.50	0.60	0.70	1.00	1.00	1.40	1.60	1.80
6.00	0.10	0.10	0.10	0.10	0.10	0.30	0.40	0.50	0.50
8.00	0.00	0.00	0.00	0.00	0.00	0.10	0.20	0.20	0.20
10.00	0.30	0.50	0.60	0.60	0.70	1.00	1.40	1.40	1.70

READINGS BY WEIGHING

h = 1.0, 3.0, 5.0 and 7.0 cm
d = 6.0 cm
D = 16.2 cm

RUN 17

h = 1.0 cm		h = 3.0 cm		h = 5.0 cm		h = 7.0 cm	
Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms
300	12.00	300	11.00	300	10.00	300	10.00
400	21.00	400	18.00	400	18.00	350	14.00
500	33.00	500	30.00	500	29.00	400	18.00
600	47.00	600	44.00	600	42.50	450	22.00
700	62.00	700	58.00	700	59.00	500	28.00
800	85.00	800	72.00	800	68.00	550	34.00
900	109.00	900	94.00	900	92.00	600	41.00
1000	135.00	1000	111.00	1000	115.00	700	52.00
1100	161.00	1100	135.00	1100	134.00	800	72.00
1200	191.00	1200	165.00	1200	160.00	1000	110.00
1300	226.00	1300	190.00	1300	182.00	1200	160.00
1400	275.00	1400	220.00	1400	210.00	1400	215.00

h = 1.0, 3.0, 5.0 and 7.0 cm
d = 7.9 cm
D = 16.2 cm

RUN 18

h=1.0 cm		h=3.0 cm		h=5.0 cm		h=7.0 cm	
Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms
200	12.00	130	4.00	170	5.50	150	4.00
250	17.00	190	8.00	250	12.00	160	5.50
300	26.00	225	12.00	300	18.00	190	7.50
350	35.00	270	16.00	350	25.00	250	16.00
400	45.00	300	19.00	400	34.00	350	28.00
450	57.00	350	29.00	450	42.00	400	38.00
500	75.00	400	35.00	500	51.00	500	57.00
55	86.00	450	43.00	550	62.00	600	82.00
600	105.00	500	55.00	600	72.00	700	114.00
700	141.00	550	67.00	700	97.00	800	148.00
800	175.00	600	78.00	800	127.00	900	196.00
900	221.00	700	105.00	900	160.00		
		800	130.00				
		900	170.00				

APPENDIX III

50 PER CENT AQUEOUS GLYCEROL DATA

Speed in rpm
Pressure (Pr) in cm of 50 per cent Aq. Glycerol
Radius in cm

RUN 19

h = 1.0 cm; d = 6.0 cm ; D = 16.2 cm

Speed	460	500	600	700	850	1000	1100	1200	1300
Radius	Pr	Pr	Pr	Pr	Pr	Pr	Pr	Pr	Pr
0.00	0.20	0.40	0.90	1.60	2.10	2.40	3.00	3.75	5.00
1.30	0.50	0.90	1.60	2.80	3.50	4.50	5.50	6.60	7.50
2.60	0.70	1.20	1.75	3.10	4.10	4.90	6.10	8.40	9.60
3.90	-0.10	-0.10	-0.20	-0.30	-0.40	-0.40	-0.50	-0.60	-0.60
5.20	-0.10	-0.30	-0.50	-0.70	-0.80	-1.00	-1.10	-1.30	-1.30
6.50	0.00	-0.10	-0.20	-0.20	-0.40	-0.40	-0.50	-0.70	-0.70
7.80	0.00	0.00	0.00	0.10	0.20	0.30	0.50	0.80	1.00

h = 3.0 cm; d = 6.0 cm ; D = 16.2 cm

RUN 20

Speed	500	700	750	850	1000	1100	1250	1350
Radius	Pr	Pr	Pr	Pr	Pr	Pr	Pr	Pr
0.00	0.10	0.50	0.70	1.40	1.90	2.60	5.50	4.50
1.30	0.20	0.90	1.60	2.30	2.90	4.00	5.00	5.80
2.60	0.30	1.30	1.90	2.50	3.20	4.00	1.70	6.30
3.90	0.10	0.30	0.30	0.30	0.30	0.40	0.80	1.00
5.20	0.00	-0.10	-0.40	-0.50	-0.70	-0.90	-0.90	-1.00
6.50	0.00	-0.10	-0.10	-0.20	-0.20	-0.30	-0.30	-0.50
7.80	0.10	0.20	0.20	0.30	0.40	0.50	0.70	0.90

h = 5.0 cm ; d = 6.0 cm ; D = 16.2 cm

RUN 21

Speed / Radius	550 Pr	600 Pr	700 Pr	850 Pr	950 Pr	1100 Pr	1200 Pr	1300 Pr
0.00	0.00	0.00	0.00	0.10	0.30	0.50	1.00	1.30
1.30	0.00	0.00	0.10	0.70	1.10	2.10	3.00	3.90
2.60	0.10	0.20	0.50	1.10	1.40	2.30	2.90	3.50
3.90	0.15	0.30	0.50	0.40	0.60	0.80	0.80	0.50
5.20	0.10	0.10	0.10	-0.20	-0.30	-0.40	-0.60	-0.80
6.50	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.20
7.80	0.20	0.30	0.30	0.50	0.50	0.50	0.60	0.60

h = 7.0 cm ; d = 6.0 cm ; D = 16.2 cm

RUN 22

Speed / Radius	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr
0.00	0.10	0.20	0.20	0.30	0.40	0.50
1.30	0.30	0.40	0.50	0.60	0.80	1.00
2.60	0.60	0.90	1.00	1.20	1.70	2.20
3.90	0.50	0.60	0.70	0.90	1.30	1.30
5.20	0.10	0.10	0.10	0.10	0.10	0.10
6.50	0.20	0.30	0.30	0.40	0.60	0.60
7.80	0.70	0.80	0.90	1.20	1.60	1.70

h = 1.0 cm ; d = 7.9 cm ; D = 16.2 cm

RUN 23

Speed / Radius	450 Pr	470 Pr	830 Pr	880 Pr	960 Pr	1040 Pr
0.00	0.90	1.20	4.00	4.50	4.50	5.90
1.30	1.20	1.80	5.90	6.80	7.30	8.90
2.60	1.30	1.80	5.70	6.90	7.70	9.50
3.90	0.30	0.30	0.60	0.70	0.90	1.00
5.20	-0.30	-0.40	-1.40	-1.60	-1.70	-2.10
6.50	-0.10	-0.20	-0.60	-0.80	-1.00	-1.20
7.80	0.00	0.20	0.50	0.80	1.00	1.40

h = 3.0 cm ; d = 7.9 cm ; D = 16.2 cm

RUN 24

Speed / Radius	420 Pr	450 Pr	500 Pr	600 Pr	800 Pr	900 Pr	1000 Pr
0.00	0.10	0.25	0.50	0.60	1.30	1.90	2.20
1.30	0.20	0.40	0.70	1.20	3.30	1.50	5.20
2.60	0.40	0.50	0.90	1.30	3.00	4.00	4.40
3.90	0.30	0.30	0.40	0.50	0.70	0.90	1.20
5.20	0.00	-0.10	-0.30	-0.40	-0.50	-0.80	-1.00
6.50	0.00	0.00	-0.10	-0.10	-0.10	-0.50	-0.50
7.80	0.30	0.30	0.50	0.60	1.00	1.20	1.30

h = 5.0 cm ; d = 7.9 cm ; D = 16.2 cm

RUN 25

Speed / Radius	300 Pr	370 Pr	450 Pr	610 Pr	880 Pr	960 Pr	1040 Pr
0.00	0.10	0.20	0.40	0.80	1.60	1.70	2.20
1.30	0.10	0.30	0.50	0.30	2.00	2.40	3.10
2.60	0.20	0.40	0.60	0.90	1.80	2.10	2.70
3.90	0.10	0.20	0.30	0.30	0.60	0.60	0.80
5.20	-0.10	-0.10	-0.10	-0.10	-0.30	-0.40	-0.70
6.50	0.00	0.10	0.20	0.30	0.50	0.50	0.50
7.80	0.10	0.20	0.40	0.60	1.30	1.40	1.70

h = 7.0 cm ; d = 7.9 cm ; D = 16.2 cm

RUN 26

Speed / Radius	450 Pr	530 Pr	880 Pr	960 Pr	1040 Pr
0.00	0.10	0.20	0.40	0.60	0.80
1.30	0.20	0.30	0.60	0.90	1.20
2.60	0.30	0.40	1.00	1.40	1.80
3.90	0.10	0.10	0.60	0.30	0.90
5.20	0.00	0.00	0.00	0.00	0.00
6.50	0.20	0.30	0.50	0.60	0.70
7.80	0.30	0.40	1.00	1.30	1.60

h = 5.0 cm ; d = 6.0 cm ; D = 21.5 cm

RUN 27

Speed / Radius	500 Pr	600 Pr	800 Pr	900 Pr	1100 Pr	1200 Pr	1300 Pr	1400 Pr
0.00	0.00	0.30	0.60	0.90	1.60	2.00	2.80	3.70
2.00	0.20	0.60	1.00	1.50	2.50	3.20	6.50	8.50
4.00	0.10	0.60	1.00	1.40	1.90	1.90	1.90	1.90
6.00	0.00	0.00	0.00	-0.10	-0.20	- 0.30	-0.40	-0.60
8.00	0.00	-0.10	-0.10	-0.10	-0.30	-0.50	-0.60	-0.60
10.00	0.00	0.20	0.30	0.40	0.60	0.60	0.80	0.80

h = 7.0 cm ; d = 6.0 cm ; D = 21.5 cm

RUN 28

Speed / Radius	800 Pr	900 Pr	1100 Pr	1200 Pr	1300 Pr	1400 Pr	1500 Pr
0.00	0.40	0.50	1.00	1.00	1.30	1.70	1.90
2.00	0.80	0.80	2.80	3.50	4.50	5.40	6.30
4.00	0.80	0.90	1.40	1.50	1.80	2.10	2.30
6.00	0.10	0.10	- .20	-0.40	-0.40	-0.50	-0.60
8.00	0.10	0.10	-0.30	-0.50	-0.60	-0.80	-1.00
10.00	0.20	0.30	0.30	0.30	0.30	0.40	0.60

h = 9.0 cm ; d = 6.0 cm ; D = 21.5 cm

RUN 29

Speed	800	900	1000	1100	1200	1300	1400	1500
Radius	Pr	Pr	Pr	Pr	Pr	Pr	Pr	Pr
0.00	0.10	0.20	0.40	0.40	0.50	0.90	0.90	1.00
2.00	0.10	0.30	0.40	0.90	1.00	1.60	1.70	2.10
4.00	0.20	0.70	0.90	1.40	1.80	1.90	2.20	2.50
6.00	0.10	0.20	0.30	0.40	0.40	0.40	0.40	0.40
8.00	0.20	0.20	0.20	0.20	0.20	-0.10	-0.20	-0.30
10.00	0.30	0.40	0.50	0.50	0.50	0.60	0.90	0.90

h = 13.0 cm ; d = 6.0 cm ; D = 21.5 cm

RUN 30

Speed	600	800	900	1000	1100	1200	1300	1400	1500
Radius	Pr	Pr	Pr	Pr	Pr	Pr	Pr	Pr	Pr
0.00	0.10	0.20	0.20	0.30	0.40	0.40	0.50	0.80	1.00
2.00	0.10	0.20	0.20	0.30	0.40	0.40	0.50	0.80	1.00
4.00	0.10	0.20	0.20	0.30	0.40	0.50	0.60	0.80	0.90
6.00	0.10	0.20	0.30	0.30	0.40	0.50	0.60	0.70	0.80
8.00	0.10	0.20	0.30	0.30	0.40	0.50	0.60	0.70	0.80
10.00	0.30	0.40	0.50	0.50	0.60	0.80	0.90	1.00	1.20

h = 1.0 cm ; d = 7.9 cm ; D = 21.5 cm

RUN 31

Speed / Radius	600 Pr	700 Pr	800 Pr	900 Pr	1200 Pr	1300 Pr	1400 Pr
0.00	1.90	2.90	3.80	5.00	6.20	7.60	8.40
2.00	1.50	2.00	3.00	4.30	5.30	6.60	7.50
4.00	1.50	2.00	3.20	4.20	4.90	6.00	7.00
6.00	0.00	0.00	0.00	-0.10	-0.20	-0.20	-0.30
8.00	-0.10	-0.10	-0.10	-0.30	-0.30	-0.40	-0.60
10.00	0.50	0.70	1.20	1.50	1.80	2.20	2.50

h = 3.0 cm ; d = 7.9 cm ; D = 21.5 cm

RUN 32

Speed / Radius	500 Pr	600 Pr	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr	1400 Pr
0.00	0.80	0.90	2.00	3.30	3.80	4.70	5.50	6.80	7.60
2.00	0.90	1.60	4.00	5.00	6.30	7.30	9.30	9.70	11.70
4.00	0.80	1.00	1.40	2.00	2.60	4.30	4.90	5.90	7.20
6.00	0.00	-0.10	-0.30	-0.30	-0.30	-0.40	-0.50	-0.60	-0.60
8.00	0.00	-0.20	-0.50	-0.50	-0.60	-0.80	-1.00	-1.00	-1.20
10.00	0.34	0.40	0.50	0.80	1.00	1.30	1.50	2.00	2.80

h = 7.0 cm ; d = 7.9 cm ; D = 21.5 cm

RUN 33

Speed / Radius	600 Pr	850 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr	1400 Pr
0.00	0.50	0.80	1.00	1.20	1.50	1.70	2.10
2.00	0.70	1.10	1.40	1.80	1.90	2.80	3.00
4.00	0.80	1.40	1.60	1.90	2.10	2.90	3.50
6.00	0.10	0.30	0.50	0.70	0.90	0.90	1.20
8.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10
10.00	0.30	0.80	0.80	1.30	1.30	2.00	2.00

h = 13.0 cm ; d = 7.9 cm ; D = 21.5 cm

RUN 34

Speed / Radius	450 Pr	650 Pr	800 Pr	900 Pr	1000 Pr	1100 Pr	1250 Pr	1350 Pr	1400 Pr
0.00	0.10	0.30	0.50	0.50	0.80	1.10	1.50	1.80	2.00
2.00	0.20	0.30	0.60	0.60	1.00	1.30	1.70	2.00	2.20
4.00	0.20	0.40	0.60	0.60	1.00	1.30	1.90	2.10	2.40
6.00	0.10	0.30	0.40	0.40	0.60	0.60	0.70	0.90	1.10
8.00	0.10	0.20	0.30	0.40	0.50	0.60	0.60	0.80	0.90
10.00	0.20	0.30	0.60	.60	0.90	1.00	1.20	1.70	1.90

READINGS BY WEIGHING

h = 1.0, 3.0, 5.0 and 7.0 cm
d = 6.0 cm
D = 16.2 cm

RUN 35

h=1.0 cm		h = 3.0 cm		h =5.0 cm		h = 7.0 cm	
Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms
1300	295.00	1300	240.00	1300	220.00	1350	230.00
1200	250.00	1200	205.00	1200	185.00	1250	195.00
1100	200.00	1100	170.00	1100	155.00	1100	155.00
1000	170.00	1000	135.00	1000	125.00	1000	130.00
900	131.00	900	110.00	900	105.00	900	105.00
800	108.00	800	90.00	800	80.00	800	80.00
700	73.00	700	63.00	700	55.00	700	60.00
600	56.00	600	44.00	600	44.00	600	48.00
500	36.00	500	30.00	500	26.00	500	31.00
400	21.00	400	18.00	400	16.00	400	18.00
						300	10.00

h = 1.0, 3.0, 5.0 and 7.0 cm
d = 7.9 cm
D = 16.2 cm

RUN 36

h=1.0 cm		h=3.0 cm		h=5.0 cm		h=7.0 cm	
Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms
1000	340.00	1000	250.00	1000	240.00	1000	260.00
900	270.00	900	210.00	900	195.00	900	205.00
800	220.00	800	170.00	800	150.00	800	160.00
700	160.00	700	125.00	700	115.00	700	127.00
600	120.00	600	95.00	600	86.00	600	98.00
550	101.00	550	76.00	550	72.00	550	76.00
500	82.00	500	65.00	500	60.00	500	68.00
450	68.00	450	50.00	450	46.00	450	52.00
400	45.00	400	36.00	400	37.00	400	41.00
350	33.00	350	25.00	350	27.00	350	32.00
300	24.00	300	17.00	300	20.00	300	22.00
250	14.00	250	11.00	250	11.00	250	15.00
200	9.00	200	7.00	200	7.00	200	9.00
				150	4.00	150	4.00

h = 1.0, 3.0, 5.0, 7.0, 8.5 and 10.5 cm
h_d = 1.0 cm, 2.9 cm, 4.1 cm and 5.3 cm
d = 7.9 cm
D = 16.2 cm

RUN 37 h_d = 1.0 cm

Speed	h=1.0 cm Wt. gms C	h=1.0 cm Wt. gms AC	h=3.0 cm Wt. gms C	h=3.0 cm Wt. gms AC	h=5.0 cm Wt. gms C	h=5.0 cm Wt. gms AC	h=7.0 cm Wt. gms C	h=7.0 cm Wt. gms AC	h=8.5 cm Wt. gms C	h=8.5 cm Wt. gms AC	h=10.5 cm Wt. gms C	h=10.5 cm Wt. gms AC
1	2	3	4	5	6	7	8	9	10	11	12	13
300	40	80	20	50	18	35	20	30	18	37		
400	65	105	30	65	28	47	30	50	29	62		
500	95	160	50	90	44	70	40	70	40	88		
600	135	220	70	120	60	90	55	90				
700	175	290	105	160	80	120	70	120				
800			145	200	105	150	97	150				
900			200	250	140	170	120	180				
h_d = 2.9 cm												
300	45	15	34	13	23	24	15	25			15	35
400	62	26	50	20	35	30	22	35			25	46
500	90	40	70	30	50	40	35	45			37	70
600	119	55	95	35	72	50	50	60			55	95
700	160	73	130	45	92	65	70	70			60	125
800	205	98	160	55	125	80	90	90				
900	255	120	200	70	155	110	115	115				
1000	315	145	250	85	190	120	145	135				

APPENDIX IV

60 PER CENT AQUEOUS GLYCEROL DATA

READINGS BY WEIGHING

h = 1.0, 3.0, 5.0 and 7.0
d = 6.0 cm
D = 16.2 cm

RUN 38

h=1.0 cm		h = 3.0 cm		h=5.0 cm		h=7.0 cm	
Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms
450	27.00	450	23.00	450.	23.00	450	25.00
550	42.00	550	35.00	550	37.00	550	40.00
600	52.00	600	45.00	600	45.00	600	50.00
800	85.00	800	72.00	800	72.00	800	77.00
1000	145.00	1000	118.00	1000	110.00	1000	110.00
1300	270.00	1300	210.00	1300	220.00	1300	200.00

h = 1.0, 3.0, 5.0 and 7.0 cm
d = 7.9 cm
D = 16.2 cm

RUN 39

400	30.00	400	27.00	400	36.00	400	35.00
500	54.00	500	48.00	500	52.00	500	55.00
600	80.00	600	72.00	600	75.00	600	80.00
800	140.00	800	122.00	800	110.00	800	119.00

APPENDIX V

MUSTARD OIL DATA

Speed in rpm
Pressure (Pr) in cm of mustard oil
Radius in cm

RUN 40

Speed / Radius	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr	1400 Pr	1500 Pr	1600 Pr	1700 Pr
0.00	0.30	0.40	0.60	0.70	1.20	1.70	2.00	2.50	2.90	3.50
1.30	0.50	0.80	1.00	1.50	2.10	2.60	3.00	3.50	4.00	4.70
2.60	1.00	1.90	2.50	3.50	4.70	5.70	6.00	6.40	7.10	7.50
3.90	0.30	0.50	0.60	0.90	1.00	1.10	1.50	1.80	2.10	2.60
5.20	0.00	-0.10	-0.30	-0.50	-0.80	-0.90	-0.90	-0.90	-0.90	-0.90
6.50	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.40
7.80	0.30	0.30	0.30	0.40	0.40	0.50	0.50	0.50	1.00	1.00

h = 3.0 cm ; d = 6.0 cm ; D = 16.2 cm

RUN 41

Speed / Radius	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr	1400 Pr	1500 Pr	1600 Pr	1700 Pr
0.00	-0.30	-0.40	-0.60	-0.60	-0.60	-0.30	-0.30	0.00	0.30	0.60
1.30	-0.30	-0.40	-0.50	-0.50	-0.50	-0.10	-0.10	0.50	0.70	1.10
2.60	0.00	0.10	0.30	0.50	0.90	1.20	1.40	2.00	2.10	2.40
3.90	0.60	0.90	1.10	1.30	1.50	1.80	1.90	2.10	2.30	2.40
5.20	0.30	0.30	0.40	0.40	0.40	0.40	0.40	0.50	0.50	0.50
6.50	0.40	0.40	0.50	0.50	0.50	0.60	0.80	1.00	1.00	1.10
7.80	0.50	0.60	0.90	0.90	1.00	1.00	1.30	1.50	1.70	1.90

h = 5.0 cm ; d = 6.0 cm; D = 16.2 cm

RUN 42

Speed / Radius	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1400 Pr	1600 Pr
0.00	0.10	0.00	-0.20	-0.40	-0.40	-0.40	-0.40
1.30	0.20	0.00	-0.20	-0.30	-0.40	-0.40	-0.40
2.60	0.20	0.10	-0.00	-0.10	-0.10	-0.20	0.30
3.90	0.20	0.20	0.30	0.30	0.40	0.70	0.80
5.20	0.30	0.30	0.40	0.50	0.50	0.80	0.90
6.50	0.50	0.60	0.60	0.70	0.70	1.00	1.10
7.80	0.60	0.70	0.80	0.90	1.00	1.20	1.50

h = 7.0 cm ; d = 6.0 cm; D = 16.2 cm

RUN 43

Speed / Radius	900 Pr	1000 Pr	1600 Pr
0.00	0.30	0.40	0.50
1.30	0.30	0.40	0.70
2.60	0.30	0.50	0.80
3.90	0.30	0.40	0.90
5.20	0.30	0.30	0.90
6.50	0.40	0.40	1.10
7.80	0.50	0.50	1.40

h = 1.0 cm ; d = 7.9 cm ; D = 16.2 cm

RUN 44

Speed / Radius	700 Pr	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr	1400 Pr	1500 Pr
0.00	0.10	0.30	0.40	1.00	1.40	2.20	2.40	3.10	4.00
1.30	0.30	0.50	0.80	1.50	2.00	2.90	3.20	4.20	5.30
2.60	1.40	2.00	2.60	2.90	4.60	4.60	5.40	6.50	7.60
3.90	0.70	0.90	1.50	1.70	2.40	3.00	3.20	3.50	3.90
5.20	-0.20	-0.30	-0.40	-0.70	-0.90	-1.00	-1.10	-1.30	-1.30
6.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.80	0.20	0.30	0.40	0.60	0.50	0.90	1.00	1.20	1.50

h = 3.0 cm ; d = 7.9 cm ; D = 16.2 cm

RUN 45

Speed / Radius	500 Pr	600 Pr	700 Pr	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr	1400 Pr	1500 Pr	1600 Pr
0.00	-0.20	-0.30	-0.30	-0.40	-0.40	-0.50	-0.50	-0.40	-0.30	0.00	0.10	0.20
1.30	-0.20	-0.30	-0.20	-0.40	-0.40	-0.50	-0.50	-0.20	0.00	0.40	0.60	1.00
2.60	0.00	0.10	0.10	0.20	0.40	0.70	1.00	1.40	1.30	2.60	3.20	4.00
3.90	0.20	0.40	0.50	0.70	1.00	1.10	1.60	2.10	2.50	3.00	3.50	4.00
5.20	0.20	0.20	0.30	0.40	0.40	0.50	0.50	0.70	0.30	0.90	0.90	0.90
6.50	0.20	0.30	0.50	0.50	0.60	0.60	0.30	1.00	1.20	1.40	1.50	1.60
7.80	0.40	0.50	0.60	0.80	0.90	1.10	1.30	1.60	1.50	2.20	2.50	2.60

h = 5.0 cm ; d = 7.9 cm ; D = 16.2 cm

RUN 46

Speed / Radius	500 Pr	700 Pr	800 Pr	900 Pr	1000 Pr	1100 Pr	1200 Pr	1300 Pr	1600
0.00	0.10	0.20	0.20	0.20	0.20	0.10	0.00	-0.10	-0.20
1.30	0.10	0.20	0.20	0.20	0.20	0.10	0.00	-0.10	-0.20
2.60	0.10	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.40
3.90	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	1.00
5.20	0.10	0.30	0.40	0.50	0.60	0.80	0.90	1.00	1.10
6.50	0.20	0.50	0.50	0.70	0.90	1.10	1.30	1.70	1.60
7.80	0.20	0.60	0.70	1.00	1.10	1.40	1.60	1.90	2.30

h = 7.0 cm ; d = 7.9 cm ; D = 16.2 cm

RUN 47

Speed / Radius	600 Pr	800 Pr	1000 Pr	1200 Pr	1400 Pr	1600 Pr
0.00	0.10	0.30	0.50	0.50	1.00	1.10
1.30	0.20	0.40	0.50	0.70	1.30	1.40
2.60	0.20	0.40	0.60	0.80	1.40	1.50
3.90	0.20	0.30	0.60	0.80	1.40	1.60
5.20	0.20	0.30	0.50	0.70	1.20	1.50
6.50	0.20	0.50	0.60	0.80	1.40	1.60
7.80	0.20	0.50	0.70	0.90	1.50	1.90

DATA BY WEIGHING

h = 1.0, 3.0, 5.0 and 7.0 cm
d = 6.0 cm
D = 16.2 cm

RUN 48

h=1.0 cm		h=3.0 cm		h = 5.0 cm		h = 7.0 cm	
Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms
300	10.00	300	9.00	300	10.00	300	14.00
400	17.00	400	14.00	400	15.00	400	20.00
500	20.00	500	19.00	500	23.00	500	30.00
600	30.00	600	26.00	600	35.00	600	38.00
700	35.00	700	41.00	700	47.00	700	52.00
800	50.00	800	56.00	800	60.00	800	65.00
900	72.00	900	67.00	900	76.00	900	83.00
1000	94.00	1000	90.00	1000	95.00	1000	96.00
1100	115.00	1100	105.00	1100	105.00	1100	119.00
1200	130.00	1200	123.00	1200	120.00	1200	137.00
1300	155.00	1300	145.00	1300	135.00	1300	168.00
1400	190.00	1400	175.00	1400	155.00	1400	195.00
1500	210.00	1500	195.00	1500	180.00	1500	230.00
1600	240.00	1600	220.00	1600	200.00	1600	212.00
1700	270.00	1700	240.00	1700	230.00	1700	250.00

h = 1.0, 3.0, 5.0 and 7.0 cm
d = 7.9 cm
D = 16.2 cm

RUN 49

h=1.0 cm		h=3.0 cm		h=5.0 cm		h=7.0 cm	
Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms	Speed rpm	Weight gms
300	15.00	300	14.00	300	12.00	300	18.00
400	25.00	400	20.00	400	20.00	400	29.00
500	45.00	500	35.00	500	30.00	500	35.00
600	60.00	600	50.00	600	50.00	600	50.00
700	80.00	700	66.00	700	65.00	700	70.00
800	107.00	800	90.00	800	88.00	800	92.00
900	140.00	900	115.00	900	115.00	900	115.00
1000	170.00	1000	145.00	1000	144.00	1000	150.00
1100	205.00	1100	180.00	1100	163.00	1100	180.00
1200	250.00	1200	217.00	1200	200.00	1200	210.00
1300	295.00	1300	260.00	1300	220.00	1300	245.00

APPENDIX VI

DISTILLED WATER TABLES

$h = 1.0$ cm ; $d = 6.0$ cm, $D = 16.2$ cm ; $d_1^{-} = 8.06$cm ;
$d_2^{+} = 13.52$ cm Pressure Profile

TABLE 1

Speed RPM	$Re \cdot 10^{-4}$	E_u	F_1 N	F_2 N	F_3 N	F_{ax} N	K_{bt_1}	K_{bt_3}
1500	9.16	0.43	3.533	1.110	1.096	3.519	0.735	0.485
1400	8.54	0.45	3.096	0.937	0.992	3.149	0.783	0.494
1300	7.93	0.46	2.723	0.762	0.818	2.779	0.796	0.484
1200	7.32	0.43	2.249	0.691	0.651	2.209	0.784	0.467
1100	6.71	0.43	1.740	0.449	0.583	1.874	0.752	0.482
1000	6.10	0.46	1.514	0.368	0.493	1.639	0.772	0.488
900	5.49	0.44	1.224	0.323	0.387	1.288	0.771	0.480
800	4.88	0.44	0.951	0.194	0.267	1.024	0.765	0.450
775	4.73	0.45	0.904	0.150	0.222	0.976	0.734	0.423
650	3.96	0.44	0.644	0.129	0.155	0.670	0.775	0.420

$h = 3.0$ cm ; $d = 6.0$ cm ; $D = 16.2$ cm ; $d_1^+ = 7.41$ cm; $d_2^+ = 13.52$ cm Pressure Profile

TABLE 2

E_u	0.284	0.264	0.282	0.300	0.274
Re x 10^{-4}	4.88	4.27	3.66	3.05	2.74
K_{bt_1}	0.694	0.699	0.619	0.648	0.678
K_{bt_3}	0.730	0.728	0.648	0.682	0.663

$h = 5.0$ cm ; $d = 6.0$ cm ; $D = 16.2$ cm ; $d_1^+ = 9.62$ cm $d_2^+ = 12.48$ cm Pressure Profile

TABLE 3

E_u	0.348	0.350	0.360	0.354	0.365	0.350	0.376	0.348	0.346
Re x 10^{-4}	9.16	8.54	7.93	7.50	7.01	6.40	5.79	4.88	4.27
K_{bt_1}	0.734	0.732	0.745	0.713	0.726	0.739	0.735	0.748	0.759
K_{bt_3}	0.576	0.565	0.566	0.550	0.551	0.560	0.588	0.488	0.488

$h = 7.0$ cm $\quad d = 6.0$ cm $\quad D = 16.2$ cm $\quad d_1^+ = 10.1$[illegible] cm,
$d_2^+ = 12.29$ cm Pressure Profile

TABLE 4

E_u	0.314	0.318	0.322	0.311	0.315	0.32[illegible]	0.302	0.[illegible]17	0.301	[illegible]
$Re \times 10^{-4}$	9.16	8.54	7.93	7.32	6.71	6.1[illegible]	5.49	5.12	4.57	3.[illegible]
K_{bt_1}	0.664	0.674	0.675	0.670	0.651	0.674	0.649	0.651	.644	0.[illegible]
K_{bt_3}	0.589	0.593	0.595	0.574	0.613	0.59[illegible]	0.598	0.538	0.614	[illegible]

NOTE: $d_1^+ = d_2^+ = 11.70$ cm at $h = 8.0$ cm $\quad d = 6.0$ cm $\quad D = 16.2$ cm Pressure Profile

$h = 1.0$ cm $\quad d = 7.9$ cm $\quad D = 16.2$ cm $\quad d_1^+ = 9.25$ cm $\quad d_2^+ = 13.00$ cm
Pressure Profile

TABLE 5

E_u	0.254	0.239	0.242	0.246	0.227
$Re \times 10^{-4}$	10.60	8.46	7.40	5.28	4.25
K_{bt_1}	0.457	0.409	0.407	0.469	0.467
K_{bt_3}	0.313	0.323	[illegible]	0.255	0.357

TABLE 6

$h = 3.0$ cm $d = 7.9$ cm $D = 16.2$ cm $d_1^+ = 9.36$ cm

$d_2^+ = 13.52$ cm Pressure Profile

E_u	0.148	0.160	0.152	0.153	0.145	0.148	0.148	0.159
$Re \times 10^{-4}$	12.70	11.60	10.60	9.51	8.46	7.40	6.34	5.28

TABLE 7

$h = 5.0$ cm $d = 7.9$ cm $D = 16.2$ cm $d_1^+ = 10.40$ cm

$d_2^+ = 12.48$ cm Pressure Profile

E_u	0.163	0.162	0.160	0.167	0.153	0.164	0.172	0.169	0.164	0.150
$Re \times 10^{-4}$	13.70	12.70	11.60	10.60	9.51	8.46	7.40	6.87	6.34	4.97
K_{bt_1}	0.377	0.386	0.375	0.375	0.366	0.363	0.372	0.374	0.360	0.337
K_{bt_3}	0.310	0.297	0.300	0.307	0.294	0.315	0.316	0.287	0.296	0.298

$h = 5.0$ cm $d = 7.9$ cm $D = 16.2$ cm $d_1^+ = 11.70$ cm

$d_2^+ = 11.70$ cm Pressure Profile

TABLE 8

E_u	0.166	0.168	0.190	0.161	0.140	0.155	0.169	0.159	0.162
$Re \times 10^{-4}$	13.70	12.70	11.60	10.60	9.51	8.46	6.87	5.81	4.86
K_{bt_1}	0.395	0.386	0.369	0.390	0.355	0.383	0.393	0.377	0.421
K_{bt_3}	0.354	0.358	0.350	0.340	0.323	0.331	0.355	0.347	0.305

TABLE 9

$h = 5.0$ cm $d = 6.0$ cm $D = 21.5$ cm $d_1^+ = 10.6$ cm $d_2^+ = 18.4$ cm

Pressure Profile

E_u	0.370	0.359	0.361	0.378	0.364	0.363
$Re \times 10^{-4}$	8.537	7.317	6.707	6.402	5.061	5.659
K_{bt_1}	1.099	1.131	1.135	1.050	1.062	1.200
K_{bt_3}	0.397	0.348	0.374	0.296	0.313	0.348

$h=7.0$ cm $d = 6.0$ cm $D = 21.5$ cm $d_1^+ = 11.00$ cm $d_2^+ = 18.40$ cm
Pressure Profile

TABLE 10:

E_u	0.288	0.275	0.319	0.324	0.305	0.288	0.308	0.300	0.318	0.3[illegible]
$Re \times 10^{-4}$	8.842	8.537	7.927	7.317	6.402	5.488	4.878	4.268	4.146	3.35[illegible]

TABLE 11 $h=9.0$ cm $d=6.0$ cm $D=21.5$ cm $d_1^+ = 11.8$ cm $d_2^+ = 18.00$ cm Pressure Profile

E_u	0.240	0.238	0.255	0.239	0.295	0.235	0.267
$Re \times 10^{-4}$	8.537	7.927	6.707	6.098	5.488	4.878	4.573
K_{bt_1}	0.996	0.958	1.015	0.967	1.004	0.926	0.923
K_{bt_3}	0.324	0.315	0.328	0.329	0.400	0.332	0.354

$h=13.00$ cm $d=6.0$ cm $D=21.5$ cm $d_1^+=16.00$ cm $d_2^+=16.00$ cm

Pressure Profile

TABLE 12

E_u	0.310	0.313	0.318	0.305	0.312	0.314
$Re \times 10^{-4}$	9.147	8.537	6.707	5.488	4.756	3.659
K_{bt_1}	1.151	1.114	1.103	1.043	1.196	1.118
K_{bt_3}	0.628	0.506	0.559	0.578	0.313	0.407

$h=1.0$ cm $d=7.9$ cm $D=21.5$ cm $d_1^+=10.40$ cm $d_2^+ = 18.00$ cm

Pressure Profile

TABLE 13

E_u	0.331	0.333	0.330	0.327	0.338	0.328	0.335	0.331	0.334	0.313	0.346	0.324
$Re \times 10^{-4}$	14.797	13.739	12.683	11.626	10.569	9.512	8.455	7.398	6.370	5.813	4.228	3.171
K_{bt_1}	0.695	0.699	0.705	0.713	0.733	0.675	0.717	0.700	0.659	0.683	0.698	0.765
K_{bt_3}	0.363	0.341	0.345	0.326	0.309	0.338	0.342	0.354	0.361	0.315	0.360	0.322

$h=3.0$ cm $d=7.9$ cm $D=21.5$ cm $d_1^+=10.60$ cm $d_2^+=17.60$ cm

Pressure Profile

TABLE 14

E_u	0.277	0.275	0.279	0.266	0.266	0.271	0.271	0.301	0.250	0.265
$Re\times10^{-4}$	14.268	13.211	12.154	11.097	10.041	9.301	8.138	6.870	6.024	5.285

$h=7.0$ cm $d=7.9$ cm $D=21.5$ cm $d_1^+=13.00$ cm $d_2^+=17.4$ cm

Pressure Profile

TABLE 15

E_u	0.236	0.241	0.222	0.249	0.250	0.231	0.248	0.230	0.238
$Re\times10^{-4}$	14.797	12.683	11.626	10.569	9.512	8.984	7.298	6.870	5.496

$h=13.0$ cm $d=7.9$ cm $D=21.5$ cm $d_1^+=15.00$ cm $d_2^+=15.00$ cm

Pressure Profile

TAPLE 16

E_u	0.181	0.177	0.196	0.162	0.181	0.168	0.182	0.214	0.180
$Re\times10^{-4}$	13.739	12.683	11.626	10.569	9.512	8.455	7.398	6.341	5.285

d=6.0 cm D = 16.2 cm WEIGHING

TABLE 17

h=1.0 cm		h=3.0 cm		h=5.0 cm		h=7.0 cm	
E_u	$Re \times 10^{-4}$	E_u	$Re \times 10^{-4}$	E_u	$Re \times 10^{-4}$	E_u	$Re \times 10^{-4}$
0.382	8.54	0.306	8.54	0.292	8.54	0.300	8.54
0.365	7.93	0.306	7.93	0.293	7.93	0.303	7.32
0.362	7.32	0.312	7.32	0.303	7.32	0.300	6.10
0.363	6.71	0.305	6.71	0.302	6.71	0.307	4.88
0.368	6.10	0.303	6.10	0.313	6.10	0.290	4.27
0.367	5.49	0.316	5.49	0.310	5.49	0.312	3.66
0.362	4.88	0.307	4.88	0.329	4.88	0.306	3.35
0.345	4.27	0.322	4.27	0.290	4.27	0.306	3.05
0.356	3.66	0.322	3.66	0.322	3.66	0.296	2.74
0.360	3.05	0.327	3.05	0.316	3.05	0.307	2.44
0.358	2.44	0.307	2.44	0.307	2.44	0.312	2.10
0.364	1.86	0.333	1.86	0.303	1.86	0.304	1.86

d=7.9 cm   D=16.2 cm   WEIGHING

TABLE 18

h=1.0 cm		h=3.0 cm		h=5.0 cm		h=7.0 cm	
E_u	$Re \times 10^{-4}$	E_u	$Re \times 10^{-4}$	E_u	$Re \times 10^{-4}$	E_u	$Re \times 10^{-4}$
0.251	9.52	0.191	9.52	0.180	9.52	0.219	9.52
0.248	8.46	0.185	8.46	0.180	8.46	0.209	8.46
0.261	7.41	0.195	7.41	0.180	7.41	0.211	7.41
0.265	6.35	0.197	6.35	0.182	6.35	0.207	6.35
0.258	5.82	0.201	5.82	0.186	5.82	0.207	5.28
0.272	5.28	0.200	5.28	0.185	5.28	0.216	4.24
0.256	4.76	0.193	4.76	0.189	4.76	0.208	3.70
0.253	4.24	0.199	4.24	0.193	4.24	0.232	2.64
0.260	3.72	0.215	3.70	0.185	3.70	0.189	2.01
0.262	3.17	0.192	3.17	0.182	3.17	0.195	1.69
0.248	2.64	0.199	2.86	0.174	2.64	0.215	1.37
0.272	2.12	0.216	2.38	0.173	1.79		
		0.201	2.10				
		0.215	1.37				

APPENDIX VII

50 PER CENT AQUEOUS GLYCEROL TABLE

h=1.0 d=6.0 cm D=16.2 cm d_1^+ = 7.54 cm d_2^+ =14.17 cm

Pressure Profile

TABLE 19

E_u	0.374	0.350	0.351	0.356	0.360	0.359	0.260	0.244	0.221
$Re x 10^{-4}$	1.64	1.52	1.39	1.26	1.08	0.858	0.759	0.632	0.582
K_{bt_1}	0.803	0.803	0.806	0.819	0.814	0.847	0.775	0.727	0.609
K_{bt_3}	0.199	0.199	0.164	0.161	0.190	0.129	0.00	0.000	0.000

h=3.0 cm d=6.0 cm D=16.2 cm d_1^+=8.26 cm d_2^+ =13.59 cm

Pressure Profile

TABLE 20

E_u	0.291	0.291	0.291	0.300	0.271	0.239	0.204	0.150
$Re x 10^{-4}$	1.71	1.58	1.39	1.26	1.08	0.949	0.885	0.632
K_{bt_1}	0.703	0.698	0.721	0.716	0.740	0.702	0.578	0.416
K_{bt_3}	0.258	0.266	0.270	0.272	0.255	0.234	0.205	0.210

$h=5.0$ cm $d=6.0$ cm $D=16.2$ cm $d_1^+=8.97$ cm $d_2^+=12.74$ cm

Pressure Profile

TABLE 21

E_u	0.242	0.232	0.230	0.231	0.246	0.220	0.208	0.177
$Re\times10^{-4}$	1.64	1.52	1.39	1.20	1.08	0.885	0.759	0.696
K_{bt_1}	0.645	0.638	0.620	0.592	0.571	0.518	0.000	0.000
K_{bt_3}	0.316	0.312	0.331	0.383	0.428	0.382	0.000	0.000

$h=7.0$ cm $d=6.0$ cm $D=16.2$ cm $d_1^+=11.18$ cm $d_2^+=11.18$ cm

Pressure Profile

TABLE 22

E_u	0.332	0.359	0.307	0.327	0.326	0.328
$Re\times10^{-4}$	1.64	1.52	1.39	1.26	1.14	1.01
K_{bt_1}	0.721	0.731	0.669	0.657	0.690	0.672
K_{bt_3}	0.285	0.307	0.287	0.312	0.295	0.306

$h=1.0$cm $d=7.9$ cm $D=16.2$ cm $d_1^+=9.49$cm $d_2^+=15.6$ cm

Pressure Profile

TABLE 23

E_u	0.215	0.203	0.215	0.215	0.219	0.169
$Re \times 10^{-4}$	2.28	2.10	1.93	1.82	1.04	0.987
K_{bt_1}	0.609	0.598	0.621	0.614	0.603	0.546
K_{bt_3}	0.089	0.084	0.081	0.062	0.072	0.000

$h=3.0$ cm $d=7.9$ cm $D=16.2$ cm $d_1^+=10.01$ cm $d_2^+=14.30$ cm

Pressure Profile

TABLE 24

E_u	0.169	0.186	0.186	0.171	0.152	0.142	0.134
$Re \times 10^{-4}$	2.19	1.97	1.75	1.32	1.09	0.987	0.921
K_{bt_1}	0.480	0.496	0.487	0.470	0.428	0.377	0.355
K_{bt_3}	0.175	0.190	0.178	0.205	0.200	0.170	0.183

$h=5.0$ cm $d=7.9$ cm $D=16.2$ cm $d_1^+=10.53$ cm $d_2^+=1$[illegible]$.39$ cm

Pressure Profile

TABLE 25

E_u	0.166	0.161	0.180	0.161	0.164	0.149	0.111
$Rc\times10^{-4}$	2.28	2.10	1.93	1.35	0.938	0.822	0.647
K_{bt_1}	0.408	0.395	0.403	0.151	0.134	0.175	0.161
K_{bt_3}	0.291	0.284	0.305	0.321	0.352	0.333	0.285

$h=7.0$ cm $d=7.9$ cm $D=16.2$ cm $d_1^+=12.09$ cm $d_2^+=12.09$ cm

Pressure Profile

TABLE 26

E_u	0.155	0.157	0.146	0.149	0.156
$Rc\times10^{-4}$	2.28	2.10	1.93	1.17	0.998
K_{bt_1}	0.385	0.386	0.359	0.343	0.329
K_{bt_3}	0.329	0.333	0.331	0.352	0.335

$h=5.0$ cm $d=6.0$ cm $D=21.5$ cm $d_1^+=11.2$ cm

$d_2^+=17.2$ cm Pressure Profile

TABLE 27

E_u	0.398	0.403	0.387	0.411	0.467	0.409	0.417	0.136
$Re \times 10^{-4}$	1.77	1.64	1.52	1.39	1.14	1.01	0.759	0.634
K_{bt_1}	1.107	1.122	1.077	1.073	1.089	1.023	1.043	0.609
K_{bt_3}	0.439	0.473	0.469	0.512	0.571	0.598	0.542	0.000

$h=7.0$ cm $d=6.0$ cm $D=21.5$ cm Pressure Profile

TABLE 28

E_u	0.309	0.293	0.291	0.288	0.326	0.338	0.367
$Re \times 10^{-4}$	1.89	1.77	1.64	1.52	1.39	1.14	1.01

h=9.0 cm d=6.0 cm D=21.5 cm d_1^+=13.4 cm

d_2^+=15.40 cm Pressure Profile

TABLE 29

E_u	0.313	0.319	0.336	0.362	0.375	0.351	0.302	0.223
$Re\times10^{-4}$	1.89	1.77	1.64	1.52	1.39	1.26	1.14	1.01
K_{bt_1}	1.031	1.018	1.039	1.052	1.048	0.984	0.906	0.621
K_{bt_3}	0.577	0.619	0.611	0.668	0.729	0.771	0.707	0.783

h=13.0 cm d=6.0 cm D=21.5 cm d_1^+=15.00 cm

d_2^+=15.00 cm Pressure Profile

TABLE 30

E_u	0.376	0.373	0.361	0.326	0.324	0.308	0.341	0.333	0.310
$Re\times10^{-4}$	1.89	1.77	1.64	1.52	1.39	1.26	1.14	1.01	0.759
K_{bt_1}	1.013	1.009	0.864	0.895	0.951	0.925	0.882	0.851	0.989
K_{bt_3}	0.896	0.940	0.887	0.933	0.987	0.950	1.026	0.999	1.210

$h=1.0$ cm $d=7.9$ cm $D=21.5$ cm $d_1^+=11.62$ cm

$d_2^+=16.98$ cm Pressure Profile

TABLE 31

E_u	0.351	0.350	0.321	0.400	0.392	0.331	0.338
$Re x 10^{-4}$	3.07	2.85	2.63	1.97	1.75	1.53	1.32
K_{bt_1}	0.731	0.739	0.736	0.875	0.861	0.795	0.783
K_{bt_3}	0.318	0.326	0.339	0.418	0.446	0.375	0.364

$h=3.0$ cm $d=7.9$ cm $D=21.5$ cm $d_1^+=11.62$ cm

$d_2^+=18.12$ cm Pressure Profile

TABLE 32

E_u	0.300	0.281	0.284	0.291	0.282	0.254	0.215	0.218	0.369
$Re x 10^{-4}$	3.07	2.85	2.63	2.41	2.19	1.97	1.75	1.32	1.10
K_{bt_1}	0.748	0.735	0.749	0.755	0.737	0.712	0.694	0.673	0.645
K_{bt_3}	0.265	0.234	0.230	0.230	0.224	0.192	0.166	0.194	0.195

$h=7.0$ cm $d=7.9$ cm $D=21.5$ cm Pressure Profile

TABLE 33

E_u	0.250	0.254	0.231	0.253	0.200	0.223	0.232
$Re \times 10^{-4}$	3.07	2.85	2.63	2.41	2.19	1.86	1.32

$h=13.0$ cm $d=7.9$ cm $D=21.5$ cm $d_1^+=14.28$ cm
$d_2^+=14.28$ cm Pressure Profile

TABLE 34

E_u	0.207	0.226	0.220	0.213	0.220	0.174	0.201	0.186	0.180
$Re \times 10^{-4}$	3.07	2.96	2.74	2.41	2.19	1.97	1.75	1.43	0.987
K_{bt_1}	0.612	0.595	0.607	0.567	0.566	0.490	0.527	0.542	0.515
K_{bt_3}	0.547	0.531	0.497	0.531	0.554	0.509	0.547	0.479	0.496

d=6.0 cm   D=16.2 cm   Weighing

TABLE 35

h=1.0 cm		h=3.0 cm		h=5.0 cm		h=7.0 cm	
E_u	$Re\times10^{-4}$	E_u	$Re\times10^{-4}$	E_u	$Re\times10^{-4}$	E_u	$Re\times10^{-4}$
0.382	8.54	0.306	8.54	0.292	8.54	0.300	8.54
0.365	7.93	0.306	7.93	0.293	7.93	0.303	7.32
0.362	7.32	0.312	7.32	0.305	7.32	0.300	6.10
0.363	6.71	0.305	6.71	0.302	6.71	0.307	4.88
0.368	6.10	0.303	6.10	0.313	6.10	[illegible]	4.27
0.367	5.49	0.316	5.49	0.310	5.49	0.312	3.66
0.362	4.88	0.307	4.88	0.290	4.88	0.306	3.55
0.345	4.27	0.322	4.27	0.329	4.27	0.306	3.05
0.356	3.66	0.322	3.66	0.322	3.66	0.296	2.74
0.360	3.05	0.327	3.05	0.316	3.05	0.307	2.14
0.358	2.44	0.307	2.44	0.307	2.44	0.312	2.10
0.364	1.86	0.333	1.86	0.303	1.86	0.304	1.86

d=7.9 cm D=16.2 cm Weighing

TABLE 36

h=1.0 cm		h=3.0 cm		h=5.0 cm		h=7.0 cm	
E_u	$Re\times10^{-4}$	E_u	$Re\times10^{-4}$	E_u	$Re\times10^{-4}$	E_u	$Re\times10^{-4}$
0.251	9.52	0.191	9.52	0.180	9.52	0.219	9.52
0.248	8.46	0.185	8.46	0.180	8.46	0.209	8.46
0.261	7.41	0.195	7.41	0.180	7.41	0.211	7.41
0.265	6.35	0.197	6.35	0.182	6.35	0.207	6.35
0.258	5.82	0.201	5.82	0.186	5.82	0.207	5.28
0.272	5.28	0.200	5.28	0.185	5.28	0.216	4.24
0.256	4.76	0.193	4.76	0.189	4.76	0.208	3.70
0.253	4.24	0.199	4.24	0.193	4.24	0.232	2.64
0.260	3.72	0.215	3.70	0.185	3.70	0.189	2.01
0.262	3.17	0.192	3.17	0.182	3.17	0.195	1.69
0.248	2.64	0.199	2.86	0.174	2.64	0.215	1.37
0.272	2.12	0.216	2.38	0.173	1.79		
		0.201	2.01				
		0.215	1.37				

APPENDIX VIII

60 PER CENT AQUEOUS GLYCEROL TABLES

d=6.0 cm D=16.2 cm Weighing

TABLE 37

h=1.0 cm		h=3.0 cm		h=5.0 cm		h=7.0 cm	
E_u	$Rex10^{-3}$	E_u	$Rex10^{-3}$	E_u	$Rex10^{-3}$	E_u	$Rex10^{-3}$
0.365	4.21	0.284	4.21	0.297	4.21	0.297	4.21
0.331	3.24	0.270	3.24	0.251	3.24	0.251	3.24
0.303	2.59	0.257	2.59	0.257	2.59	0.275	2.59
0.330	1.94	0.286	1.94	0.286	1.94	0.317	1.94
0.317	1.78	0.264	1.78	0.279	1.78	0.302	1.78
0.305	1.46	0.259	1.46	0.259	1.46	0.282	1.46

d=7.9 cm D=16.2 cm Weighing

TABLE 38

h=1.0cm		h=3.0cm		h=5.0 cm		h=7.0 cm	
E_u	$Rex10^{-3}$	E_u	$Rex10^{-3}$	E_u	$Rex10^{-3}$	E_u	$Rex10^{-3}$
0.166	4.49	0.145	4.49	0.131	4.49	0.141	4.49
0.169	3.37	0.152	3.37	0.158	3.37	0.169	3.37
0.164	2.81	0.146	2.81	0.158	2.81	0.167	2.81
0.143	2.25	0.128	2.25	0.171	2.25	0.166	2.25

APPENDIX IX

MUSTARD OIL TABLES

$h=1.0$ cm $d=6.0$ cm $D=16.2$ cm $d_1^+=8.6$ cm, $d_2^+=12.62$ cm

Pressure Profile

TABLE 39

E_u	0.258	0.260	0.236	0.247	0.263	0.242	0.246	0.230	0.243	0.217
$Re \times 10^{-3}$	1.48	1.39	1.30	1.22	1.13	1.04	0.956	0.869	0.782	0.695
K_{bt_1}	0.631	0.642	0.647	0.666	0.690	0.655	0.632	0.593	0.581	0.498
K_{bt_3}	0.329	0.326	0.237	0.253	0.273	0.271	0.295	0.297	0.330	0.372

$h=3.0$ cm $d=6.0$ cm $D=16.2$ cm $d_1^+=11.28$ cm $d_2^+=11.28$ cm

Pressure Profile

TABLE 40

E_u	0.259	0.262	0.276	0.258	0.259	0.241	0.251	0.278	0.248	0.272
$Re \times 10^{-3}$	1.48	1.39	1.30	1.22	1.13	1.04	0.956	0.869	0.782	0.695
K_{bt_1}	0.639	0.654	0.662	0.651	0.665	0.623	0.609	0.614	0.598	0.589
K_{bt_3}	0.569	0.558	0.584	0.562	0.548	0.565	0.610	0.599	0.629	0.698

h=5.0 cm d=6.0 cm D=16.2 cm Pressure Profile

TABLE 41

E_u	0.173	0.191	0.167	0.166	0.175	0.205	0.269
$Re \times 10^{-3}$	1.39	1.22	1.04	0.956	0.869	0.782	0.695

h=7.0 cm d=6.0 cm D=16.2 cm Pressure Profile

TABLE 42

E_u	0.211	0.235	0.226
$Re \times 10^{-3}$	1.39	0.869	0.782

h=1.0 cm   d=7.9 cm   D=16.2 cm d_1^+=9.38 cm
d_2^+ =12.96 cm   Pressure Profile

TABLE 43

E_u	0.128	0.121	0.119	0.123	0.130	0.094	0.101	0.087	0.079
$Re \times 10^{-3}$	2.26	2.11	1.96	1.81	1.66	1.51	1.36	1.21	1.05
K_{bt_1}	0.374	0.370	0.370	0.375	0.396	0.339	0.345	0.323	0.311
K_{bt_3}	0.153	0.147	0.143	0.151	0.132	0.127	0.122	0.118	0.099

h=3.0 cm   d=7.9 cm   D=16.2 cm d_1^+=11.28 cm
d_2^+=11.28 cm   Pressure Profile

TABLE 44

E_u	0.140	0.142	0.147	0.141	0.130	0.115	0.117	0.120	0.121	0.126	0.121
$Re \times 10^{-3}$	2.50	2.26	2.11	1.96	1.81	1.66	1.51	1.36	1.21	1.05	0.904
K_{bt_1}	0.363	0.358	0.360	0.345	0.338	0.320	0.311	0.302	0.301	0.287	0.288
K_{bt_3}	0.311	0.320	0.332	0.334	0.318	0.301	0.318	0.331	0.347	0.374	0.355

h=5.0 cm d=7.9 cm D=16.2 cm Pressure Profile

TABLE 45

E_u	0.082	0.104	0.111	0.112	0.112	0.116	0.114	0.124	0.102
$Rex10^{-3}$	2.50	1.96	1.81	1.66	1.51	1.36	1.21	1.05	0.753

h=7.0 cm d=7.9 cm D=16.2 cm Pressure Profile

TABLE 46

E_u	0.118	0.135	0.106	0.087	0.096	0.109
$Rex10^{-3}$	2.50	2.11	1.81	1.51	1.21	0.904

d = 6.0 cm   D = 16.2 cm   Weighing

TABLE 47

h=1.0 cm		h=3.0 cm		h=5.0 cm		h=7.0 cm	
E_u	$Re \times 10^{-3}$	E_u	$Re \times 10^{-3}$	E_u	$Re \times 10^{-3}$	E_u	$Re \times 10^{-3}$
0.279	1.48	0.248	1.48	0.238	1.48	0.259	1.48
0.280	1.39	0.257	1.39	0.234	1.39	0.283	1.39
0.279	1.30	0.259	1.30	0.239	1.30	0.306	1.30
0.290	1.22	0.267	1.22	0.237	1.22	0.298	1.22
0.274	1.13	0.257	1.13	0.239	1.13	0.297	1.13
0.270	1.04	0.255	1.04	0.249	1.04	0.285	1.04
0.284	0.956	0.260	0.956	0.259	0.956	0.294	0.956
0.281	0.869	0.269	0.869	0.284	0.869	0.287	0.869
0.266	0.782	0.247	0.782	0.281	0.782	0.306	0.782
0.234	0.695	0.262	0.695	0.280	0.695	0.304	0.695
0.214	0.608	0.250	0.608	0.287	0.608	0.317	0.608
0.249	0.521	0.216	0.521	0.291	0.521	0.316	0.521
0.239	0.435	0.227	0.435	0.275	0.435	0.359	0.435
0.318	0.348	0.262	0.348	0.280	0.348	0.374	0.348
0.332	0.261	0.299	0.261	0.332	0.261	0.465	0.261

d=7.9 cm D =16.2 cm Weighing

TABLE 48

h=1.0 cm		h=3.0 cm		h=5.0 cm		h=7.0 cm	
E_u	$Re \times 10^{-3}$	E_u	$Re \times 10^{-3}$	E_u	$Re \times 10^{-3}$	E_u	$Re \times 10^{-3}$
0.174	1.96	0.153	1.96	0.130	1.96	0.144	1.96
0.173	1.81	0.150	1.81	0.138	1.81	0.145	1.81
0.169	1.66	0.148	1.66	0.134	1.66	0.148	1.66
0.169	1.51	0.144	1.51	0.143	1.51	0.149	1.51
0.172	1.36	0.141	1.36	0.141	1.36	0.141	1.36
0.166	1.21	0.140	1.21	0.136	1.21	0.143	1.21
0.163	1.06	0.134	1.06	0.131	1.06	0.142	1.06
0.166	0.904	0.138	0.904	0.138	0.904	0.138	0.904
0.179	0.753	0.139	0.753	0.119	0.753	0.139	0.753
0.156	0.603	0.124	0.603	0.124	0.603	0.180	0.603
0.166	0.452	0.154	0.452	0.133	0.452	0.199	0.452

APPENDIX X

TABLE 49: DEPENDENCE OF EULERS NUMBER ON h/D

d/D=0.4877		d/D=0.3704		d/D=0.3674		d/D=0.2791	
h/D	E_u	h/D	E_u	h/D	E_u	h/D	E_u
0.062	0.26	0.062	0.39	0.047	0.34	0.047	0.57
0.123^{δ}	0.22	0.123^{δ}	0.35	0.140	0.27	0.140^{δ}	0.54
0.185	0.20	0.185	0.32	0.326	0.23	0.233	0.36
0.247^{δ}	0.16	0.247	0.30	0.512^{δ}	0.14	0.326	0.30
0.309	0.19	0.309	0.30	0.605	0.18	0.419	0.25
0.370^{δ}	0.20	0.370^{δ}	0.29	-	-	0.512^{δ}	0.30
0.432	0.20	0.432	0.30	-	-	0.605	0.30

TABLE 50: DEPENDENCE OF EULERS NUMBER ON d/D

h/D=0.05		h/D=0.10		h/D=0.20	
d/D	E_u	d/D	E_u	d/D	E_u
0.4877	0.27	0.4877	0.233	0.4877	0.198
0.3704	0.42	0.3704	0.368	0.3704	0.310
0.3674	0.34	0.3674	0.295	0.3674	0.250
0.2791	0.53	0.2791	0.470	0.2791	0.394

$^{\delta}$Values not mentioned in Appendices

TABLE 51: DEPENDENCE OF d_1^+/D on h/D

d/D =0.4877		d/D=0.3704		d/D=0.3674		d/D=0.279	
h/D	d_1^+/D	h/D	d_1^+/D	h/D	d_1^+/D	h/D	d_1^+/D
0.19	0.58	0.19	0.46	0.14	0.49	0.23	0.49
0.25	0.64	0.25	0.58	0.33	0.60	0.33	0.51
0.31	0.64	0.31	0.59	0.61	0.70	0.42	0.55
0.37	0.65	0.37	0.60	-	-	0.61	0.74
0.43	0.72	0.43	0.63	-	-	-	-
-	-	0.49	0.72	-	-	-	-

TABLE 52: DEPENDENCE OF d_1^+/D ON d/D:

h/D=1.0		h/D=0.4		h/D =0.3	
d/D	d_1^+/D	d/D	d_1^+/D	d/D	d_1^+/D
0.4877	0.90	0.4877	0.70	0.4877	0.65
0.3704	0.80	0.3704	0.63	0.3704	0.58
0.3674	0.80	0.3674	0.63	0.3674	0.58
0.2791	0.71	0.2791	0.55	0.2791	0.51

TABLE 53: DEPENDENCE OF K_{bt_1} average ON h/D AND d/D:

d/D=0.4877		d/D=0.3704		d/D=0.2791		h/D=0.30	
h/D	K_{bt_1av}	h/D	K_{bt_1av}	h/D	K_{bt_1av}	d/D	K_{bt_1av}
0.047$^{\delta}$	1.206	0.062	0.772	0.062	0.438	0.4877	0.376
0.233	1.113	0.185	0.668	0.247$^{\delta}$	0.365	0.3704	0.670
0.419	0.970	0.309	0.737	0.309	0.368	0.2791	1.060
0.605	1.121	0.432	0.658	0.432	0.384	0.0000	0.000

TABLE 54: DEPENDENCE OF K_{bt_1av}/K_p ON h/D AND d/D:

d/D=0.4877		d/D=0.3704		d/D=0.2791		h/D=0.20	
h/D	$\frac{K_{bt_1av}}{K_p}$	h/D	$\frac{K_{bt_1av}}{K_p}$	h/D	$\frac{K_{bt_1av}}{K_p}$	d/D	$\frac{K_{bt_1av}}{K_p}$
0.062	0.751	0.062	1.384	0.047$^{\delta}$	2.263	0.4877	0.69
0.309	0.631	0.185	1.196	0.233	2.088	0.3704	1.23
0.432	0.659	0.309	1.320	0.419	1.820	0.2791	2.00
-	-	0.432	1.178	0.605	2.103	-	0.00

$^{\delta}$Values not mentioned in the Appendices